Predicting the future of global seafood production

by

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Table of Content

DECLARATION OF ORIGINALITY III

AUTHORITY OF ACCESS IV

STATEMENT REGARDING PUBLISHED WORK CONTAINED IN THESIS V

STATEMENT OF CO-AUTHORSHIP VI

ACKNOWLEDGMENTS III

TABLE OF CONTENT IV

LIST OF ILLUSTRATIONS AND TABLES VII

ABSTRACT X

CHAPTER 1 – INTRODUCTION. 1

CHAPTER 2 – PARAMETERS AND KNOWLEDGE NEEDED FOR DEVELOPING MORE ACCURATE FISHERIES YIELD MODELS. 4

2.1) Historical approaches to fisheries modelling. 5
2.1.1) Human activity models: catch data and economics models. 5
2.1.1.1) Direct extrapolation of catch data: from unlimited expansion to decline. 5
2.1.1.2) Stock assessment: the surplus function model. 8
2.1.1.3) Management scenarios. 8
2.1.1.4) Supply-demand models. 9
2.1.1.5) Bioeconomics models. 10
2.1.1.6) Limits of the human activity-based models. 11
2.1.2) Biological models: estimation of current and future biomass. 12
2.1.2.1) Trophic efficiency: food chain/web models. 13
2.1.2.2) Size spectrum. 14
2.1.2.3) Habitat preference: ecological forecasting. 15
2.1.2.4) Limits of biological models. 17
2.1.3) Bridging the gap: End to end models. 19

2.2) Source of uncertainty in fisheries models 20
2.2.1) Mortality from fishing. 21
2.2.2) Supply and demand from a human perspective. 23
2.2.3) The ‘human feedback’ effect on targeting. 24

2.3) Balancing knowledge gaps and complexity in fisheries models. **25**

2.4) Modelling fisheries yield: on the need to adopt transdisciplinarity to move forward. **28**

CHAPTER 3 - DEFINING GLOBAL ARTISANAL FISHERIES. **32**

3.1) Introduction. **32**

3.2) Methodology. **34**

3.3) Defining artisanal fisheries in the literature. **35**

3.4) Sectorial definitions found in legislation. **38**

3.5) For a rhetorical approach. **43**

3.6) Conclusion. **47**

CHAPTER 4 - EVOLUTION OF THE GLOBAL FISHING FLEET, ITS IMPACT AND MANAGEMENT. **50**

4.1) Introduction. **50**

4.2) Methodology. **52**
4.2.1) Data sourcing. 53
4.2.2) Data pre-processing. 53
4.2.3) Conversion of data in time series and interpolation / extrapolation of the number of vessels and engine power. 57
4.2.3.1) Definition of artisanal fisheries. 57
4.2.3.2) Separation of the data by sector. 58
4.2.3.3) Interpolation and extrapolation of the data in time series from 1950 to 2015. 59
4.2.3.4) Further extrapolation for the unpowered fleets. 61
4.2.3.5) Separation of the power data in power classes. 63
4.2.3.6) Comparative analysis of the engine power - Model creation and validation. 63
4.2.4) Defining 'similar countries'. 64
4.2.5) Validation of Reconstruction. 66
4.2.6) Effort and catch per unit of effort. 69
4.2.6.1) Days at sea. 70
4.2.6.2) Nominal effort. 72
4.2.6.3) Effective effort. 73
4.2.6.4) Catch and catch per unit of effort (CPUE). 78
4.2.7) Comparison with stock assessment data. 82

4.3) Results. **82**
4.3.1) The size and power of the global fishing fleet. 82
4.3.2) Effort and catch per unit of effort (CPUE). 87

4.4) Discussion. **90**
4.4.1) Data availability and credibility. 90
4.4.2) Quantifying fishing sectors. 92
4.4.3) Modernization of fleets and management. 94

4.5) Conclusion. **97**

CHAPTER 5 - MAPPING GLOBAL FISHERIES: BALANCING GAPS AND OVERCONFIDENCE IN DATA. 99

5.1) Introduction. 99

5.2) Data and methods. 100
5.2.1) Analysis of AIS Data. 101
5.2.1.1) Data pre-processing. 101
5.2.1.2) Linking observation rates to corruption. 102
5.2.1.3) Fishing hours. 103
5.2.2) Mapping effort data. 104
5.2.2.1) Association of effort and gears. 104
5.2.2.2) Mapping the effort. 107

5.3) Results. 108
5.3.1) Gaps in the Global Fishing Watch AIS datasets. 108
5.3.2) Comparison of the AIS data and fishing effort. 110
5.3.3) Spatial development of global fishing fleets. 113
5.3.3.1) Unpowered fishing effort. 114
5.3.3.2) Artisanal (motorised) effort. 114
5.3.3.3) Industrial effort. 115

5.4) Discussion. 117
5.4.1) Compatibility of datasets and results. 117
5.4.2) Corruption in fisheries and its impact on AIS signals. 119
5.4.3) Gaps in the AIS data. 120
5.4.4) Concept of fishing effort and implication for sectoral management. 123

5.5) Conclusion. 124

CHAPTER 6 - GENERAL DISCUSSION. 126

6.1) Understanding marine fishing fleets and their impact. 126
6.1.1) Descriptive evolution of fishing fleets. 127
6.1.2) Fishing fleets and the carrying capacity of the oceans 128
6.1.3) Limits to our understanding and the future of the fleet. 131

6.2) Understanding the future of the resource: integration of fleet components into models. 132
6.2.1) The importance of feedbacks between fleets and resources. 133
6.2.2) Conclusion: the future of seafood production. 134

APPENDIXES 136

BIBLIOGRAPHY 211

List of Illustrations and Tables

FIGURE 2.1. GLOBAL OCEANS HARVESTABLE YIELD AS ESTIMATED BY VARIOUS STUDIES. IF DIFFERENT FROM THE YEAR OF ESTIMATE, THE YEAR OF PUBLICATION IS INDICATED IN PARENTHESIS. STUDIES INDICATING A CHANGE IN YIELD WITHOUT NUMERICAL REFERENCE POINT WERE EXCLUDED. UNREVISED ESTIMATES BY THE SAME (FIRST) AUTHOR IN MULTIPLE STUDIES USING THE SAME METHODOLOGY WERE EXCLUDED. 7

FIGURE 2.2. SIMPLIFIED REPRESENTATION OF PARAMETERS USED IN A FULLY INTEGRATED SUPPLY AND DEMAND MODEL FOR GLOBAL FISHERIES. TRADE IS NOT EXPLICITLY REPRESENTED, ALTHOUGH IMPLICITLY RELATED TO MANAGEMENT, PRICE/COST AND DEMAND. 21

FIGURE 3.1. COUNTRIES NAMING SECTORS AS 'ARTISANAL' (A), 'SMALL-SCALE' (B), 'COASTAL' (C), 'SUBSISTENCE' (D) IN THEIR LEGISLATIVE FRAMEWORK, COMPARED WITH THE CONTENT OF THE DEFINITION CLASSIFIED AS 'TECHNICAL' (E), 'EXTENT' (F), 'TOPOGRAPHY' (G), AND 'USE' (H). COUNTRIES IN WHITE DO NOT REFER TO THE TERM, THE EUROPEAN UNION IS CONSIDERED UNDER THE UMBRELLA OF REGULATIONS 508/2014 AND 2015/523. ONLY THE PRINCIPAL NAME OF THE SECTOR (AND SYNONYMS IF SPECIFIED) ARE USED (I.E. IF A SECTOR NAMED 'ARTISANAL' IS DESCRIBED AS 'SMALL-SCALE' IN A LAW, THE NAME WAS CLASSIFIED AS 'ARTISANAL' AND THE DEFINITION CONSISTENT WITH 'EXTENT'. 40

FIGURE 3.2. GRAPHIC REPRESENTATION OF INDICATIVE PARAMETERS USED TO DESCRIBE ARTISANAL FISHERIES, COMPARING THE NATIONAL LEVEL OF 'ARTISANALNESS' IN ICELAND, INDONESIA AND THE UK (LEFT) AND FRANCE, PERU AND MEXICO (RIGHT). THE PARAMETERS OF DEPTH, DISTANCE AND GEOGRAPHY USE THE SAME PROXY. COMMUNITY RECOGNITION AND DAYTIME/SEASONAL FISHING WERE EXCLUDED FROM THE PARAMETRISATION, AS THEY WERE ASSUMED TO BE OF LOW SIGNIFICANCE AT THE NATIONAL LEVEL. SOURCES OF THE EXAMPLE PROXIES USED FOR QUANTIFICATION ARE PROVIDED IN THE SUPPLEMENTARY MATERIAL. ALL VALUES WERE NORMALIZED (TO 1) VIA COMPARISON WITH THE MAXIMUM FOR THE PROXY (SEE APPENDIX 2). 47

FIGURE 4.1. CONCEPTUAL DIAGRAM OF THE PROCESSES USED TO SEPARATE THE FISHING VESSEL/ENGINE POWER DATA INTO TIME SERIES AND INTERPOLATE/EXTRAPOLATE. 56

FIGURE 4.2. GROSS DOMESTIC PRODUCT (GDP) PER CAPITA AT YEAR OF PEAK UNMOTORIZED FLEET FOR 18 COUNTRIES WHICH MAXIMIZED THEIR UNPOWERED FISHING FLEET BETWEEN 1950 AND 2015. GDP PER CAPITA EXPRESSED IN 2015 US DOLLAR. 62

FIGURE 4.3. COUNTRIES WITH ACCESS TO THE HIGH SEAS SEPARATED IN SOCIOCULTURAL REGIONS. OVERSEAS TERRITORIES AND DEPENDENCIES WERE REATTACHED TO THEIR MOTHER COUNTRY. 65

FIGURE 4.4. AVERAGE LEVEL OF THE GROSS DOMESTIC PRODUCT (GDP) PER CAPITA OF THE WORLD'S COUNTRIES WITH ACCESS TO THE HIGH SEAS. OVERSEAS TERRITORIES AND DEPENDENCIES WERE REATTACHED TO THEIR MOTHER COUNTRY. 66

FIGURE 4.5. COMPARISON OF THE TOTAL ESTIMATED ENGINE POWER BETWEEN ORIGINAL ENGINE POWER DATA AND RECONSTRUCTION FROM MODELS USING ONE DATA POINT OF ENGINE POWER TAKEN IN 1960 (A), 1980 (B), 2000 (C) OR WITHOUT USE OF DATA (D). THE COMPARATIVE 'SIMILAR COUNTRIES' SUBSETS USED IN THE MODELS WERE CHOSEN SUCCESSIVELY AS THE DATA SUBSETS FROM COUNTRIES WITH BOTH THE SAME SOCIOCULTURAL REGION AND THE SAME PER CAPITA GDP CATEGORY, ONE OF THESE PARAMETERS, OR NEITHER. SEE IN TEXT COMPARATIVE ANALYSIS FOR DETAILS. . 68

FIGURE 4.6. AVERAGE NUMBER OF DAYS AT SEA PER YEAR BY GEAR TYPE. DATA SOURCE (ANTICAMARA ET AL., 2011). 71

FIGURE 4.7. AVERAGE NUMBER OF DAYS AT SEA PER YEAR BY ENGINE POWER CLASS. DATA SOURCE (ANTICAMARA ET AL., 2011). 72

FIGURE 4.8. CATCH PER UNIT OF EFFORT, NOMINAL (BLACK) AND EFFECTIVE (RED) FOR VARIOUS REGIONS OF THE WORLD, EXCLUDING THE UNPOWERED FLEET, INDEXED TO 1950. GREY AND DARK PINK SHADED AREAS CORRESPOND TO A ONE STANDARD DEVIATION ERROR (68 % CONFIDENCE INTERVAL) BASED ON THE UNCERTAINTY OF THE ENGINE POWER ALONE,

light pink shaded area corresponds to a one standard deviation error based on the uncertainty of the engine power and technological creep combined. 76
Figure 4.9. Catch per unit of effort, nominal (black) and effective (red) for various regions of the world, including the unpowered fleet, indexed to 1950. Grey and dark pink shaded areas correspond to a one standard deviation error (68 % confidence interval) based on the uncertainty of the engine power alone, light pink shaded area corresponds to a one standard deviation error based on the uncertainty of the engine power and technological creep combined. The effect of the inclusion of the unpowered fleet, comparing with Figure 4.8, is minimal and almost exclusively one of error margins. 77
Figure 4.10. Snapshots of the relative change in nominal catch per unit of effort (CPUE), indexed to 1950, from 1960 to 2010. 79
Figure 4.11. Snapshots of the relative change in effective catch per unit of effort (CPUE), indexed to 1950, from 1960 to 2010. The technological creep was chosen as 2.6% per annum. 80
Figure 4.12. Yearly change in nominal (black) and effective (red) catch per unit of effort (CPUE) by region and sector, 1950-2015, indexed to 1950. The effective CPUE assumes a 2.6% increase in technological creep per annum. Dashed lines represent the artisanal fishing sector (including powered and unpowered), dotted lines the industrial sector, and solid the total CPUE for the region regardless of sector or fleet segment. 81
Figure 4.13. Number of vessels in the global fishing fleet by country (a) and power class (b), total engine power of the global fishing fleet by country (c), power class (d), powered-artisanal (e) and industrial (f) sectors 1950-2015. Country labels (except for the European Union, EU) are expressed in ISO 3166-1 standards. 83
Figure 4.14. Snapshots of the ratio of motorization (a,b,c) and average engine power in kW (d,e,f) of the national motorized fishing fleet in 1950, 1980 and 2015, respectively. Motorization levels in European Countries in 1950 might be overestimated, due to the lack of data post World War II. No data for the unmotorized fleet of Finland was found, but it was assumed that the motorization level was close to 100% since the 70s, similar to other Scandinavian countries. 85
Figure 4.15. Comparison of the results of this study with data from previous study. The comparison includes estimates from the FAO (FAO, n.d.-d, 2011b, 2015c) and Bell et al. (Bell et al., 2017) for the number of vessels in the global unpowered (a) and motorized (b) marine fleets, and the global engine power of the marine fleet (c). 86
Figure 4.16. Yearly nominal (black) and effective (red) fishing effort by region and sector, 1950-2015, averaged per day. The effective effort assumes a 2.6% increase in technological creep per annum. Dashed lines represent the artisanal fishing sector (including powered and unpowered), and dotted lines the industrial sector. 88
Figure 4.17. Yearly change in nominal (black) and effective (red) CPUE and stock abundance (dotted blue) by region, 1950–2015, indexed to 1950. The effective CPUE assumes a 2.6% increase in technological creep per annum. The grey and dark pink shaded areas correspond to one SD error (68% confidence interval) based on the uncertainty of the engine power alone, the light pink shaded area corresponds to one SD error based on the uncertainty of the engine power and technological creep combined. Abundance was expressed in terms of the total assessed biomass or spawning biomass. The y axes were aligned to facilitate comparison. 89
Figure 4.18. Mean yearly change in nominal CPUE per country between 2000 and 2015. Countries in black do not have enough information to meaningfully calculate the rate of change according to sectors. 90
Figure 4.19. Snapshots of the 2015 relative change in nominal (a) and effective (b) catch per unit of effort (CPUE), indexed to 1950. The technological creep estimated at 2.6% per annum. 94
Figure 5.1. Methods and data source used for mapping the fishing effort. 101
Figure 5.2. Count of vessels by observation rate, 2016 Global Fishing Watch data. The observation rate was defined as the ratio of number of kilometres points at which an individual vessel was observed to the maximum distance at which the vessel was observed. 104

Figure 5.3. Total number of vessels observed at least once at distance X from the nearest shore in the Global Fishing Watch (GFW) data for 2016. The red dotted line represents the expected observation of an exponential decrease of observation with increasing distance. 108
Figure 5.4. Increasing proportion of undetected vessels compared with increasing perceived corruption, by country. Detection of vessel considered if observed at least once under 11km from the nearest coast, data from Global Fishing Watch (GFW); higher Corruption Index corresponds to lower perceived corruption by nationals, data from transparency.org. 108
Figure 5.5. Ratio of GFW estimates to modelled days at sea (a and b) and fishing hours (c and d), by perceived corruption index, 2016 data. Left column (a and c) model assumes unchanged maximum observed distance of vessels, right column (b and d) model assumes the maximum distance reached by a vessel based on averages by engine power classes and gear. Please note that high CPI corresponds to low levels of perceived corruption. 109
Figure 5.6. Fishing effort, in hours per km2 of sea, by engine power classes, from 2016 GFW data (left, a-c) and the mapped effort derived from (Rousseau, Watson, Blanchard & Fulton, 2019b) (right, d-f). 112
Figure 5.7: Evolution of the mapped fishing effort, in kW-hours per km2, by fishing sector and year. 116
Figure 6.1. Conceptual representation of the motorization of the fishing fleet of a given country. 129

Table 3.1. Number of countries using the terms ‘artisanal’, ‘coastal’, ‘small-scale’, ‘subsistence’ in their legislative framework, by main spoken language. Countries might be double counted (esp. Latin languages) due to countries with more than one official language. Although the Latin family consists of many more languages, we kept it to the three main languages spread through colonisation. ‘Unreferred’ indicates that none of the above-mentioned names are found in the legislation (although other names such as ‘traditional’ or ‘customary’ might be found). 42
Table 3.2. Aristotle’s circumstances (6Ws) applied to fishing, with example proxies chosen to establish estimates for national fleets in Figure 3.2. 46
Table 4.1. Order (from top to bottom) of the best fitted models of ratio and average engine power considered, by comparative ‘similar countries’ subset and parameters (GDP/Sociocultural region) used, depending on the availability of data source. “Some” data refers to at least one data point used in the models, of average year inside the range given by “year of data”. 69
Table 4.2. Number of marine fishing vessels and associated motor power by regions, by fishing sector, at various years. 84
Table 5.1. Number of marine vessels and their characteristics, fishing hours and total days at sea, by engine power class, derived from 2016 processed satellite data (globalfishwatch.org, left column) and 2015 effort data ((Rousseau, Watson, Blanchard & Fulton, 2019b), right column), including (top line) and excluding (bottom line) Chinese fishing fleet. 111

Abstract

Understanding the impact of global fisheries on ecological and human systems is intimately linked to the yield of the ocean, the combination of marine resources and how to access them, i.e. fishing fleets. A major current limitation is the lack of integration of fishing fleets with ecological data, critical for understanding the sustainability of global fisheries.

To address this research gap, I collected and classified 151 countries legal definitions of fishing sectors according to language, technology or fishing vessel characteristics. Based on these definitions, I reconstructed the global engine power, vessels number and fishing effort from 1950 to 2015, separating industrial and artisanal sectors. The fishing effort was then mapped, leveraging on existing mapped catch data, and compared with satellite tracking.

Various models have attempted to express the global ocean's yield, but the uncertainty was found to be vast, due to disciplinary shortcomings. Lack of harmonization of terms, particularly in fishing sector, impede the comparability of studies, and require further examination. These sectoral-specific hurdles reflected in the fishing fleets, the rate of change varying vastly between sectors. Globally, vessel numbers, engine power and fishing effort have increased in almost all regions since the 1950s. Only the most developed countries showed signs of stabilization and fleet reduction. Conversely, the global catch per unit of effort has decreased drastically since the 1950s, highlighting the strain on marine resources and hinting at future declines, particularly in Southeast Asia. Mapping of the effort confirmed the disparate nature of global fishing and highlighted the lack of detail of the artisanal sector.

Future work is required to improve estimates of fisheries efficiency. A better understanding of the global yield and the links between fisheries and the oceans might be facilitated by integrating fleets in models, which this thesis has described in detail.

Chapter 1 – Introduction.

It is widely accepted that fisheries are central to issues of global food security (FAO, 2014b), livelihood of populations (Barange et al., 2011) and global trade (Sumaila, Bellman, & Tipping, 2014), and will continue to be so in the foreseeable future. Understanding the future of seafood production is linked to our knowledge of both the oceans' resources and of the development and management of fishing fleets. Proper fisheries management, in particular, goes hand in hand with meeting the sustainable development goals (FAO, 2018).

While our understanding of the oceans' resources (seafood) has continuously developed in the last decades, our knowledge of the interaction with humans remain patchy (Galbraith, Carozza, & Bianchi, 2017), particularly in the aspects driving the global fishing fleet. With the notable exception of the United Nations' Food and Agriculture Organisation (FAO), there have been relatively few previous attempts to evaluate the size of the global fishing fleet and its effort (Anticamara, Watson, Gelchu, & Pauly, 2011; Bell, Watson, & Ye, 2017; Watson & Tidd, 2018), leading to vast uncertainties on the full extent of the direct (Britten, Dowd, & Worm, 2016; Watson et al., 2013) and indirect (Burgess et al., 2018; Parker et al., 2018) impacts of marine fisheries on the oceans biosystems.

Beyond these impacts, further detailing of the fleet is necessary for its proper management and address issues over overcapacity (Sumaila, Lam, Manach, Swartz, & Pauly, 2016) and illegal fishing (Cabral et al., 2018), and meaningfully understand its connection with other human aspects such as employment (Teh & Sumaila, 2013) or fairness (Smith, 2019).

In this thesis, I will argue that our knowledge of the global fishing fleet remains insufficient, and that careful analysis of its components and their impact is necessary in order to allow integration in global ecosystem models. Over the past century many estimates have been made of global productivity and potential harvest. These have taken many different approaches, each with their own strengths and weaknesses. A summary of those approaches is provided in Chapter 2, highlighting the needs in data collection.

I began my thesis thinking I would update and expand these approaches to make them more realistic. However, it quickly became evident that, for progress to be made, some fundamental uncertainties had to be constrained. While there have been advances in computing power and modelling frameworks over the past 50 years (Metcalfe, Righton, Hunter, Neville, & Mills, 2008), with models increasing in complexity, some biases in parameterization have remained mostly unchanged.

Landings remain one of the widest used data sources in global fisheries analyses. This is because landings data is widely available and significant effort has been put into creating representative (even potentially comprehensive) databases of global spatially allocated catch (Pauly & Zeller, 2016b; Watson, 2019). Landings, however, cannot be used as an accurate proxy for the fishing effort and, by comparison, the latter is poorly known. Not only is fleet capacity and effort not universally reported nor monitored, but details of the fleet dynamics are often excluded from global stock assessment models (Quaas, Reusch, Schmidt, Tahvonen, & Voss, 2016), or oversimplified. One aspect of this oversimplification comes from the rather limited focus on the industrial components of the fishing fleet, leaving aside a disproportionately large portion of the fleet. Chapter 3 introduces the concept of artisanal fisheries and the need to provide better definition in the scientific literature, in order to avoid the biases and uncertainties recurring in global fisheries studies.

The following chapters aim at securing strong foundations for future modelling approaches of fishing yield by expanding our understanding of global fishing fleets and historical patterns of fishing effort and power: if a good understanding of the past and current levels of fishing effort is lacking, it is likely that advice and actions will be misguided. A detailed account of the global fishing fleets in term of boat numbers and engine power, and their development since 1950 is given in Chapter 4, followed by estimates of the global fishing effort and its associated catch per unit of effort (CPUE). In Chapter 5 I further detail the global fishing fleet by associating fishing gears to the capacity provided in the previous chapters, and analyse its spatial expansion, comparing this with estimates based on 'observed' satellite data. Finally, in Chapter 6 I draw together the themes of the thesis to highlight the advances made and the gaps remaining, which can act as foci for future research.

This thesis represents a significant advancement of the global understanding of the true magnitude of fishing endeavours and the pressures they put on marine ecosystems now and in the past. The dataset derived through this work is already being widely used by the FAO and other groups to improve models of global fishing and strengthen estimates of the potential of global oceans to maintain industry and food security.

Chapter 2 – Parameters and knowledge needed for developing more accurate fisheries yield models.

Seafood production is intimately linked to the yield of the oceans, that is the combination of how much resource is available for humans to utilize from marine ecosystem as well as the techniques necessary to access them, i.e. the fishing fleet and its management. Modelling approaches, whether with complex parametrisation or simple extrapolation, are necessary to estimate global fisheries yield, as simple observation of what is taken out of the oceans in not possible, due to misreporting, illegal, unregulated and unreported (IUU) fishing, and uncertainties linked to fishing mortality.

While modelling approaches that will be described in this chapter all have their undeniable merits, I will, however, argue that many have fallen in the fallacy of looking at fisheries yield through a mono-disciplinary lens or a static view of the oceans. This has led to a narrow focus on very specific parameters in models, such as trophic efficiency in ecologic models or landed mass and value in human ones. Other parameters, particularly linking human and biologic systems, have been understated, and the dynamic aspects of these systems and their interactions are often lost. Until recently, very few studies have attempted to represent marine fisheries as a global socio-ecological system, and fewer still to predict their future. It is now understood that integrated models based on global factors are required to get a clearer picture of the future of global yields (Barange, Cheung, Merino, & Perry, 2010; Delgado, Wada, Rosegrant, Meijer, & Ahmed, 2003; Pauly et al., 2002; Thébaud et al., 2014), but yet, year-to-year, regional stock assessments remain the basis of most decision-making processes (Pauly et al., 2002).

2.1) Historical approaches to fisheries modelling.

From the various studies that have attempted to estimate the yield of global fisheries, two schools of thoughts can be discerned: those models based on human activity and those focused on biological components. From a human (socio-economics) perspective, modelling fisheries endeavours to ensure that yields will supply a changing demand and meet economic constraints and requirements, while the ecological perspective attempts to represent the complex biophysical interactions inside marine ecosystems and from that infer potential yield. The former aims at extrapolating from past trends in yield and catch, often with different management scenarios and human dynamics, while the latter aims at estimating the oceans biomass and productivity, and the portion available for harvest.

Since the 60s, many studies have attempted to estimate the potential yield of global oceans, from both perspectives (Fig. 2.1), and the results vary greatly depending on the method and parameters used. Historical approaches and their estimates, however, require a closer examination.

2.1.1) Human activity models: catch data and economics models.

2.1.1.1) Direct extrapolation of catch data: from unlimited expansion to decline.

The oceans' waters were once thought inexhaustible. Although it was understood that specific local fisheries could be depleted, it was believed that the overall abundance would allow moving from one stock to another and expanding indefinitely (Huxley, 1883). Extrapolation of local catch data to global yield was considered valid as long as new stocks could be exploited, and an overall increase in effort would increase the catch (Gulland, 1971). With future seafood supply assumed to largely exceed our needs for animal proteins, studies considered its production limited only by demand, therefore harvest would grow with human population needs (Briones, 2006). This led to unreasonable estimates of yearly growth in global fisheries catch, such as the 'conservative' 4% of Chapman (Chapman, 1970). Early concerns were not about the availability of the resource, but on its distribution (Chapman, 1970) and its socioeconomic value (Chapman, 1970; Scott, 1967).

This simplistic view has largely disappeared as the existence of a maximum yield to the seas, reachable by human technology, has been widely accepted. Graham and Edwards (Graham & Edwards, 1962), for instance, used the catch data of the North Atlantic shelf to predict a maximum global yield of 55Mt, a method later reprised by Gulland (Gulland, 1971), with updated data, to estimate the yield of 160-220Mt. These values, however, still assumed that a much greater productivity of the oceans than recent estimates, and did not take into consideration geographical variability, economical limits or technological progress, nor did it foresee the expansion of fisheries to the high seas.

This optimistic view, which lasted till the major fisheries collapses of the 70s, contrasts with the belief that wild catch fisheries have reached a plateau of 80Mt since the end of the 1980s (Merino et al., 2012) or even a more conservative position based on consideration of currently 'invisible' catch such as illegal fishing or discards (Pauly et al., 2003; Pauly & Zeller, 2016a; Watson & Pauly, 2001). Historical overfishing, in synergy with other ecological disturbances, has led to the collapse of many fish stocks (Jackson et al., 2001). Over 90% of global stocks are considered at maximum exploitation or overfished (FAO, 2014b). As simply extrapolating future availability from previous catch trends is, at best, precarious, some measure of the stock health needs to be introduced as a limit to the expansion of the fisheries. Historically this has been done by assuming the efficiency of a fishery as an input/output ratio, with catch and effort usually used as the respective indicators.

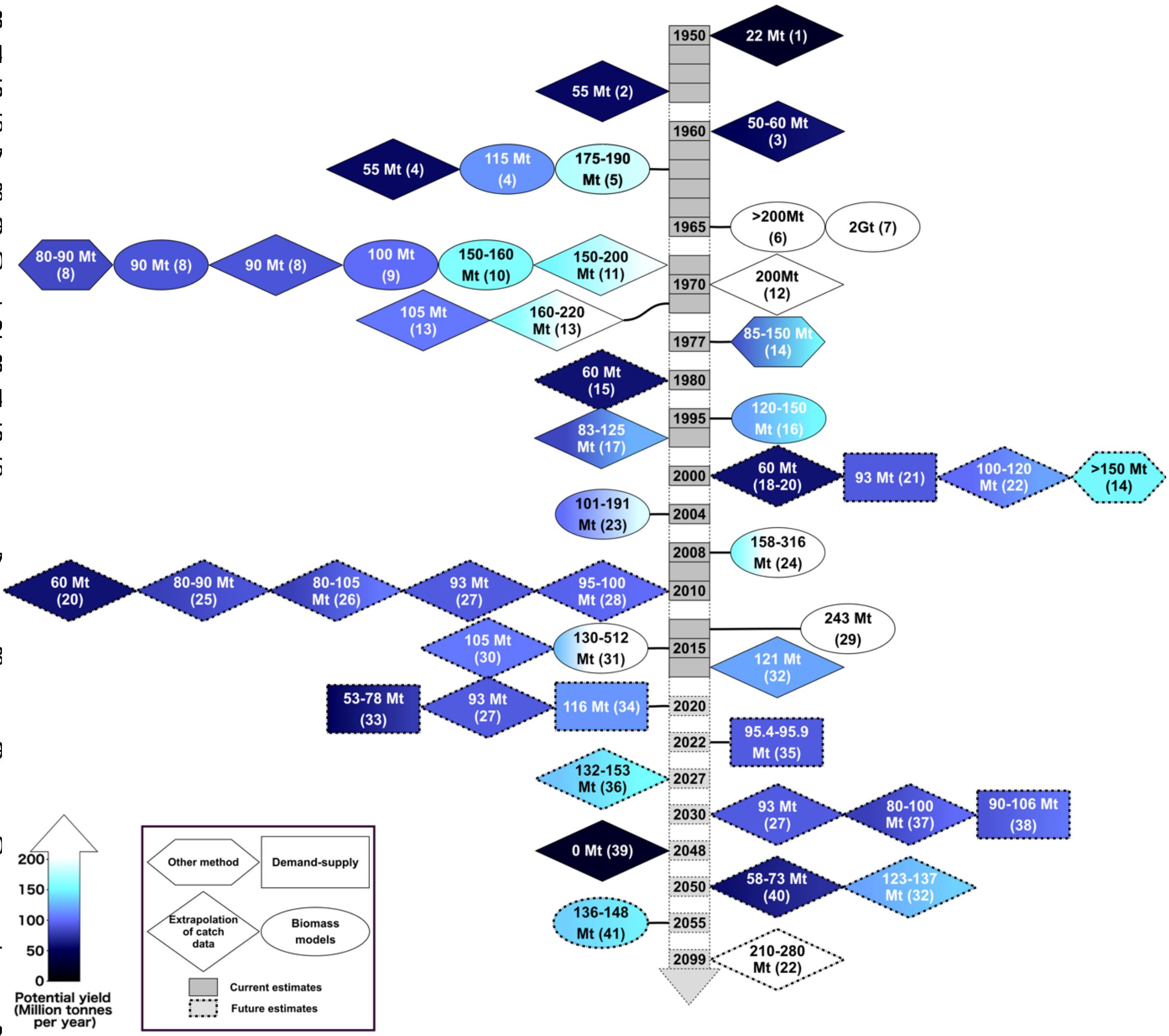


Figure 2.1. Global oceans harvestable yield as estimated by various studies. If different from the year of estimate, the year of publication is indicated in parenthesis. Studies indicating a change in yield without numerical reference point were excluded. Unrevised estimates by the same (first) author in multiple studies using the same methodology were excluded.
Sources for estimates: 1: Thompson (1950); 2: FAO (1953); 3: Finn (1960); 4: Graham & Edwards (1962); 5: Pike & Spilhaus (1962); 6: Schaefer (1965); 7: Chapman (1965); 8: Moiseev (1969); 9: Ryther (1969); 10: Ricker (1969); 11: Baird & Stratton (1969); 12: Chapman (1970); 13: Gulland (1971); 14: Ackefors (1977); 15: Meseck (1962); 16: Moiseev (1995); 17: Grainger & Garcia (1996), 18: Hennemuth (1979); 19: (Barney, 1980); 20: FAO (1995); 21: Robinson (1982); 22: Wise (1984); 23: Chassot et al. (2010); 24: Jennings et al. (2008); 25: FAO (2006c); 26: FAO (1996); 27: FAO (2002b); 28: FAO (1998); 29: Rosenberg et al. (2014); 30: FAO (2004d); 31: Jennings & Collingridge (2015); 32: Costello et al. (2016); 33: Delgado et al. (2003); 34: FAO (2004b); 35: FAO (2014); 36: del Monte-Luna et al. (2016); 37: Garcia & Grainger (2005); 38: World Bank (2013); 39: Worm et al. (2006); 40: Hilborn & Costello (2018); 41: Cheung et al. (2010).

2.1.1.2) Stock assessment: the surplus function model.

Catch data (landings) and capacity allow for the measurement of catch per unit of effort (CPUE), the most used proxy for assessing the status of a fishery (Christian Mullon, Freon, & Cury, 2005). Using CPUE data, and understanding that marine resources are limited, the surplus function model (sometimes called biomass dynamics models), based on Graham's theory (M. Graham, 1935) and expanded by Schaefer (1954) and Fox (1970), is one of the simplest stock assessment model commonly used (e.g. Costello et al., 2016). It allows for estimation of maximum sustainable yield (MSY) of a stock based solely on CPUE, without prior knowledge of biological data such as growth, natural mortality or life history parameters (Sparre & Venema, 1992). Simply put, whenever the catch does not increase anymore with increased effort, the fishery has reached its peak productivity. The earliest meta-analysis of local stock assessment was reported by Gulland (Gulland, 1971) and this method estimates a global yield of 105Mt.

CPUE remains the basis for most assessments, but is now recognised as having significant associated issues (Christian Mullon et al., 2005) and has led to some controversial estimates (Worm et al., 2006). In addition, the life history of stocks has been recognised as important (Worm et al., 2009). Consequently, predictive assessment of fisheries has more routinely explicitly recognised uncertainties and has begun utilising scenarios (Pauly et al., 2003; Worm et al., 2009).

2.1.1.3) Management scenarios.

Forecasting the future of fisheries is precarious and cannot be thought of as a simple extrapolation of present trends (Garcia & Grainger, 2005). Many uncertainties, particularly from economics and human behaviour, render the process challenging. Moving away from direct extrapolation, the importance of taking into consideration the biological state of the resource is now widely accepted (FAO, 2014b) especially in a context of food scarcity. Consideration of details pertaining to governance, management advice and responses to that have led to the development of scenario-based studies. Notably, the FAO, in its State of World Fisheries and Aquaculture (SOFIA report) has explored the potential future of global yield based on current management trends and other plausible management scenarios (FAO, 1995, 1996, 1998, 2000c, 2002b, 2004d, 2006c). Although their conclusions are almost always optimistic and predict a general increase in global yield, it leaves room for uncertainty and connection with other agricultural sectors, as well as allowing for a general socio-economic context.

Historically, management scenarios have been incorporated in global model largely as qualitative inputs. Supply -demand models, in particular, have used such scenarios for the purpose of 'story-telling', to explore the potential effects of stocks recovery or collapse (Pauly et al., 2003). Recent work has demonstrated, however, an integration of management strategies and policies in quantified form (Costello et al., 2016; Jones, Dye, Pinnegar, Warren, & Cheung, 2015).

2.1.1.4) Supply-demand models.

The concept of supply and demand has been understood for centuries, with the term first coined in the 18th century (Steuart, 1767). Simply put, the law of supply and demand states that the market price of a commodity positively affects supply and inversely affects demand, with a positive feedback from demand and a negative from supply. From a fisheries perspective, it will dictate the economics of fishing, and the influence of harvesting costs, income, prices, investment, infrastructure, effort, gear, use and trade on each other (MacKenzie, 1983). While this allows for in depth analysis of the consequences of changes in prices on the food chain supply and connected activities such as aquaculture, most supply and demand models use the yield solely as an input parameter, extrapolated from past catch data. The focus of such models is often on the effect on fish oil and fishmeal markets, and the competition with aquaculture.

For the few models considering a dynamic yield, the importance is put on investigating scenarios for the management of fisheries and potential recovery or collapse of stocks. Under business as usual management, the FAO fish model (FAO, 2014b) projected a 0.5% annual increase in capture fisheries (95Mt by 2022), while the International Food Policy Research Institute (IFPRI) IMPACT model (Delgado et al., 2003) estimated a 0.7% increase (77Mt by 2020), reviewed a decade later (World Bank, 2013) at 0.25% (93.2Mt by 2030). Although the FAO estimates are fairly independent of scenarios, the scenario specifications drastically affect the IMPACT estimates. An example of this is found in aquaculture, vastly used as a buffer in the FAO fish model, but crucial to management strategies in IMPACT. Such an inclusion leads to vastly different estimates in the global capture yields, from 53-78Mt (Delgado et al., 2003) to 90-106Mt (World Bank, 2013). These scenarios, however, lack an in-depth representation of the stock: the demand and supply models are largely devoid of important ecological production mechanisms, limiting their scope. Bioeconomics models have been introduced as an answer to this limitation of 'traditional' supply and demand models.

2.1.1.5) Bioeconomics models.

Bioeconomics models (BEM) were developed as an extension of demand and supply models. Unlike the latter, BEM explicitly include stock biomass and a production function (Clark & Munro, 1975; Gordon, 1954; Schaefer, 1954). A dynamic projection of the CPUE based from surplus theory is used as the basis for the estimation of supply (Prellezo et al., 2012), while competition and diminishing returns cap the use of the resources. Under these assumptions, the fishery is self-regulated, and cannot expand indefinitely, nor go to extinction. Nowadays, the flaws in these assumptions are recognised, for example, subsidies allow for fishing beyond the economic limit (Sumaila, Lam, Manach, Swartz, & Pauly, 2013).

Due to their supply and demand nature, BEM of future seafood production are scenario-based, leading to high variability in results. Higher demand could lead to ecological collapse and price increase (Briones, 2006), or be satisfied by increased stocks and even imply a decrease in price (Mullon et al., 2009). BEM are highly sensitive to harvesting strategies (Thébaud et al., 2014), but human behavioural patterns beyond some basic fisheries dynamics and data sampling are poorly represented (Fulton, Smith, Smith, & van Putten, 2011). A recent study (Costello et al., 2016) explored the effect of changing governance and management strategy in their BEM with 3 scenarios. Under business as usual, it showed that pressure on fish stock would increase, while a change to right-based fishery management could increase future yield to 102-116Mt (123-137Mt when including estimates for illegal fishing).

2.1.1.6) Limits of the human activity-based models.

The major disadvantage of socio-economics models is the underrepresentation of biological components. As seen with the extrapolation of past catch, this often leads to overestimation of the potential yield of the oceans. Although most research nowadays distances itself from direct extrapolation of landing data, some major studies still assume continued trends, particularly demand and supply models. For those who include MSY, CPUE is not an unbiased index of abundance (Seijo, Defeo, & Salas, 1998), and the feedback effect between fishing and biomass is rarely represented (Briones, 2006; Prellezo et al., 2012). In demand- supply models, landings are used as a proxy for the supply part of the chain, and demand is driven by population growth (FAO, 2014b; World Bank, 2013) and price of fish/income (Briones, 2006; FAO, 2014b; Mullon et al., 2009; World Bank, 2013), with little regard for the carrying capacity of global stocks.

Bioeconomics models do include a biological aspect, but although mortality, growth and recruitment are included in the relationship between effort and catch, they are oversimplified (Prellezo et al., 2012). Habitats are often poorly defined; preference and spatial variations of the stock ignored (Foley, Armstrong, Kahui, Mikkelsen, & Reithe, 2012; Seijo et al., 1998), and the effect of fishing target species on the ecosystem (and vice versa) is poorly represented. Despite being called 'bioeconomic' these models typically emphasize economics, while the biological component is kept simple, which can lead to misleading results (Prellezo et al., 2012).

Although climate change is accepted to have a major effect on marine ecosystem, no realistic scenario is used to modify the supply chain, few classic bioeconomics models include even simplified climatic assumptions - either reducing (Briones, 2006) or increasing (Mullon et al., 2009) the future biomass of oceans. This is, however, rapidly changing, as integrated climatic- economics-biological models are being developed (e.g. Carozza et al., 2016; Carozza, 2015).

Furthermore, a major drawback of the human activity models is that they rely heavily on actual reports of the activity, i.e. the fishing fleet, and a common bias in scientific literature is that a subset of the global fishing fleet is often used as a global representation, such that fleets from the developed countries are used to infer those from the poorest nations (Bell et al., 2017) or that all global fleets are represented by only the 'industrial' sector. The recent advances in satellite (vessel signal) data might give the impression that the global fishing fleet is known with high detail, while actually only a fraction, usually the largest vessels, are monitored (Kroodsma et al., 2018).

2.1.2) Biological models: estimation of current and future biomass.

While the human activity models focus on the end-side of the fishing process, management and economic activities, biological models reflect the physical aspect of the oceans, particularly ecosystem. At their heart, they attempt to link changes in primary productivity (PP) to ecosystem and fish productivity (Dulvy et al., 2009). Although the quantification of phytoplankton has been of interest since the late 19th century (Hensen (1899), in Nielsen (1960)), the global harvest potential of the seas has only become a question for the scientific community in the 1960s (Graham & Edwards, 1962). The development of new methods from sampling phytoplankton (Nielsen, 1960; Ryther, 1969) and the remote sensing of the pigment chlorophyll A (Neville & Gower, 1977) has allowed for clearer estimates of global PP. This has led to the first estimates of oceans productivity, with quantified PP as the base link of food chain theories.

2.1.2.1) Trophic efficiency: food chain/web models.

Such models aim at representing a food chain, or food webs, including the relationships between consumers and their prey. A key parameter in these models is the biological assimilation efficiency (Lindeman, 1942), also known as transfer efficiency, which assesses the percentage of prey biomass turned into living tissue by predators. This parameter is of critical importance to estimate the biomass of higher trophic levels, typically the targets of our fisheries (Gulland, 1971). Similar to terrestrial ecosystems, fisheries yields are ultimately limited by photosynthesis and the primary production of the oceans.

Earlier estimates of transfer efficiency used a fixed percentage of 10-25%, leading to estimates of biomass of higher trophic organisms ranging from 200Mt to over 2Gt (Chapman, 1965; Graham & Edwards, 1962; Gulland, 1971; Moiseev, 1969, 1995; Ryther, 1969; Schaefer, 1965). In the past few decades, this was narrowed to a mean estimate of approximately 10% (Pauly & Christensen, 1995). This is, however, well known to be a mean value, and more representative of the efficiency of higher trophic levels, with lower trophic levels (especially amongst the zooplankton groups) potentially having much higher levels. It is also widely accepted that models should not assume that efficiency is constant at each level of the food chain (Gulland, 1971; Pauly & Christensen, 1995; Rosenberg et al., 2014; Ryther, 1969). A FAO working group (Rosenberg et al., 2014) expanded the method and used probability distribution for transfer efficiencies to estimate a global biomass of 1.75 Gt (excluding benthos).

Many ecosystem models have, however, moved away from simple transfer efficiencies as an input, with linear exchanges up a food chain. Instead, models with a richer representation of food web links have been used. Using Ecopath (with Ecosim), a mass-balance model, the global fish biomass was estimated to be 1.1Gt (Christensen & Walters, 2004; Christensen et al., 2009). A limitation of these models is, however, their high data requirements (Latour, Brush, & Bonzek, 2003) – e.g. input estimates of biomass, production and consumption rates (Polovina, 1984). Furthermore, ecosystem models are often sensitive to the assumed food web structure, the particular network of links between consumers and their prey, which is often not well known. Recent studies have questioned our knowledge and accuracy in parameterizing such models (Irigoien et al., 2014).

2.1.2.2) Size spectrum.

To overcome some of the limits in complexity of mass balance models at the global level, alternative model types have been proposed. For example, models which use theories of energy transfer between predators and prey, based on biomass body-size spectra (Kerr & Dickie, 2001). Sheldon et al. (Sheldon, Prakash, & Sutcliffe, 1972), counting particles across oceans, discovered a logarithmic relationship between abundance and mass. This relationship was expanded to variables such as richness, abundance, range size, trophic level and body size across ecosystems, no matter their composition (Barange et al., 2011; Jennings et al., 2008). At the simplest level, size spectrum analysis uses these correlations to predict consumer biomass and production based on PP, body mass, temperature and mass specific rates of production (Jennings et al., 2008; Jennings & Blanchard, 2004).

Using this approach, the global fish biomass was estimated at 0.9- 1.4Gt (Jennings et al., 2008; Jennings & Collingridge, 2015).

As fishing is a size-selective process, size-based models can be used to represent fish communities in a simpler, more usable fashion than food web models (Pope, Rice, Daan, Jennings, & Gislason, 2006). The main disadvantage of the theory is that it does not, *a priori*, deal with the specific of species, and the composition of the ecosystem, of critical importance for fisheries targeting. Recent models, however, have coupled the theory with food webs and created size-structured, multispecies models (Blanchard et al., 2014; Scott, Blanchard, & Andersen, 2014).

A definite advantage of size spectra is that their relative simplicity means that integration within a supply and demand framework should be relatively straightforward, as they can output size classes readily usable as proxy for fishmeal or fish oil (Blanchard et al., 2012; Merino et al., 2012). Other socioeconomic extensions of size spectrum are equally possible. The BOATS model, for instance, uses simplified size spectra inside a bioeconomics model to explicit an "earth-system approach to modelling fish biomass at the global scale" (Carozza et al., 2016).

2.1.2.3) Habitat preference: ecological forecasting.

The structure of the predator prey relationship is not the only parameter for determining biomass, productivity and yield. Habitat quality is of prime importance when considering the potential biomass of an ecosystem. Not just for demersal stocks who are obviously habitat dependent (e.g. coral reef fish), but also pelagic stocks which target specific environmental conditions. Moreover, changes in temperature or pH might greatly affect species abundance and distribution (IPCC, 2014). Quantifying that change, however, is a much more difficult problem, and more frequently, therefore, predictions use ecological forecasting (Clark, 2001).

From an abundance perspective, changes in climatic conditions and ocean chemistry will strongly affect PP and therefore total productivity of an ecosystem (Barange et al., 2010; Cheung, Close, Lam, Watson, & Pauly, 2008; Cheung et al., 2010). Uncertainty associated with the PP change, however, is high (Cheung et al., 2010; Dulvy et al., 2009; Jones et al., 2015; Sarmiento et al., 2004). The response of biological rates such as mortality, growth and recruitment is equally uncertain (Britten et al., 2016; Jennings & Brander, 2010; Rijnsdorp, Peck, Engelhard, Mollmann, & Pinnegar, 2009). From a distribution perspective, although a wide shift is expected from changing climate (Jones et al., 2015; Sunday et al., 2015), particularly on targeted species (Cheung, Jones, et al., 2016; Cheung et al., 2010; Sunday et al., 2015), the details of the shifting mechanism remain unclear. The certainty about which traits affects the shifting of single species remains low (Sunday et al., 2015) and expands badly to whole ecosystems (Cheung, Jones, et al., 2016; Friedland et al., 2012; Lehodey et al., 2006; Perry, 2005). Recent studies have described the effect of temperature on biological rates (Jennings et al., 2008; Jennings & Collingridge, 2015), but published models focusing on the impact of changing climatic conditions on ecosystems and communities at global scale remain scarce (Barange et al., 2011; Christensen et al., 2015; Jennings & Brander, 2010), although growing in numbers.

A series of marine ecological forecasting studies, using 'bioenvelope' modelling (Cheung, Frölicher, et al., 2016; Cheung, Jones, et al., 2016; Cheung et al., 2010), attempted to predict the effect of climate change on global fisheries potential. According to these studies, the catch potential of tropical regions could decrease, while those of Arctic grounds increase by up to 50% (Cheung, Jones, et al., 2016; Cheung et al., 2010). The fate of Antarctic fisheries, however, is highly uncertain, and the variability in these shifts is high. Shifts in range-based models are highly dependent on the algorithms used (Cheung, Frölicher, et al., 2016; Cheung, Jones, et al., 2016), particularly since these works focused on single species, not entire ecosystems upon which they are dependent. The more recent studies, however, seem to attempt to at least partially address this by building in more ecological mechanisms to do with production, habitat dependency etc.

2.1.2.4) Limits of biological models.

With increasing complexity of biological theories, variability in the results is highly dependent on the quantification of parameters and the representation of the food web and its constituent functional groups. In most biomass-oriented models, the disagreement stems from the parameterization of trophic efficiency and energy conversion, whether fixed through the entire ecosystem (Irigoien et al., 2014; Jennings et al., 2008) or species-dependent (Christensen et al., 2015, 2009; Jennings & Collingridge, 2015; Rosenberg et al., 2014; Wilson et al., 2009). Most studies have used 'classic' estimates in the order of 5-20% across the food web to derive a global fish biomass of the order of billions of tonnes. These estimates, however, are contradicted by an echo-sounder survey (Irigoien et al., 2014), which directly measured a biomass ten-fold greater. Their model was capable of reproducing this order of magnitude by assuming that over 70% of the phytoplankton is consumed in the ocean instead of the "classic" 10%.

Global biological models, unlike regional ones, have largely focused on estimating the current biomass rather that its future. Although more recently developed models are seeing this change via contributions to the Fisheries Model Intercomparison Project (FISHMIP, www.isimip.org). Not unlike extrapolation from catch data, predicting future yield from biomass estimates is challenging. Long abandoned is the idea that the future of stocks depends only on what men will want them to be (Kesteven, 1962). A growing (but currently still small) number of studies give explicit values on the impact of environmental changes on the global biomass (Blanchard et al., 2012; Carozza, 2015; Cheung, Jones, et al., 2016; Cheung et al., 2010; Merino et al., 2012). Moreover, while the impact of changing environmental conditions on biological rates per species might be being studied (e.g. via laboratory studies), much less is known about effects on interactions inside a system (Griffith & Fulton, 2014).

Even when biomass and productivity are estimated, translating the results from biological models to estimates of a harvestable portion for fisheries management is difficult. What is harvestable varies ultimately with targeting, itself highly dependent on size selectivity and management scenarios (Jennings & Brander, 2010; Jennings & Collingridge, 2015), and indeed on the capacity of fishing fleets. For instance, Graham and Edwards (1962) considered that 50% of the productivity of the oceans is harvestable, while the FAO working group establish a range of 10-90% depending on functional groups (Rosenberg et al., 2014). The question of the harvestable portion of the ocean is of great complexity, as it varies with the definition of what is considered a harvestable stock (i.e. something that is palatable or has some other use) and stock sustainability. Bridging the gap between these estimates of biomass and their effect on fisheries yield is a challenging exercise that is not often openly discussed in such terms in while little attention has been paid in global model-based papers to the proportion of productivity available for harvest it has been a topic of major debate in fisheries for decades (as it is ultimately what is being considered when setting target and limit reference points). Few studies attempt to give an explicit answer from a biological perspective (Jennings & Collingridge, 2015; Rosenberg et al., 2014), or even attempt to reconstruct historical catch data from a biological model perspective, though some notable exceptions (Blanchard et al., 2012; Christensen et al., 2015) are found and models participating in FISHMIP will need to attempt such reconstructions Added to this is the further complication that even now the estimates of PP required to sustain current needs are uncertain (Dulvy et al., 2009; Jennings et al., 2008; Pauly & Christensen, 1995). The link between PP and fisheries yield is equally problematic, displaying strong local connections (at least in some locations) but becoming incoherent at larger scales, i.e. globally (Friedland et al., 2012).

2.1.3) Bridging the gap: End to end models.

The field of fisheries is at the intersection of scientific, social, economic, ecological and technological considerations, there is, however, traditionally often been little communication across disciplines (Fulton, Smith, et al., 2011; Thébaud et al., 2014). Most studies have focused on economics, and ignored the biological component (Briones, 2006); or have concentrated on stock assessment with little consideration for the human factors (Barange et al., 2011, 2010; Fulton, Smith, et al., 2011). In order to capture the seafood production system, measured trade-offs are necessary (Thébaud et al., 2014). Representation of extended food webs might require a focus on key species and a decrease in resolution away from target species (deYoung, 2004).

In recent years, so called end-to-end (E2E) models have started to emerge, aiming at representing abiotic, food web, feedbacks from climate forcing and anthropogenic impacts as integrated models (Dulvy et al., 2009; Rose et al., 2010; Travers, Shin, Jennings, & Cury, 2007). All are extremely complex (e.g. Barange et al., 2011), given the number of functional groups, species and interactions, but few, however, capture fisheries as a global, multidisciplinary system (Travers et al., 2007), tending to have a regional focus instead. Furthermore, while there is pressure to give simple answers to this ever increasing complexity (Griffith & Fulton, 2014), the choice of parameters and management scenario lead to extreme variability in models output (Cheung, Frölicher, et al., 2016). The focus of E2E is somehow linked to the focus of the disciplines it is based on, each with its own biases and variability (Griffith & Fulton, 2014), somehow limiting the connectivity between components. Strong links, however, exist between biological and human models, and the parameterisation of these should be at the base of future models. Given the pressure on ocean's production, there must be a strong focus on integrating the disparate research elements and on validating these models with historical trends.

2.2) Source of uncertainty in fisheries models.

The question of global oceans yield, often pondered in the 1960s, somehow fell out of fashion in the 1970s, coincident with a (temporary) loss of faith in mechanistic ecosystem modelling approaches. Climate change, the application of ecological theories and strong advances in computing power have renewed the interest in the last decade, and vastly increased the complexity of recent models. While the pressure to build extensive E2E models is increasing, the computing power and data required for global models is often prohibitive (Barange et al., 2011; Rose et al., 2010), and this has led to trade-offs in parameterization and a renewed call for some degree of simplicity, at least intermediate complexity (Plagányi, 2007).

When drawing up intermediate complexity models it is good to begin with a conceptual diagram of the system, so key features can be selected for further quantitative representation. In that context, every global fisheries model can be thought of as a special case of a generic demand and supply model (Fig. 2). Pure biological approaches do not focus on the demand side, while catch extrapolation methods ignore the supply chain. At the intersection, bioeconomic models and surplus production methodologies encompass both aspects of supply and demand, without necessarily going into enormous detail on either component. While there is a need for development of the E2E models, which can tackle both branches, there is an equally important need to develop the framework for these models. To increase their rigor and to allow for scenarios (e.g. of management, technology and legal changes) to be appropriately included as parameters. While models have increased in complexity over the last half-century, some biases in parameterization have remained mostly unchanged, in particular the impact and drivers of human activities such as fishing mortality and targeting.

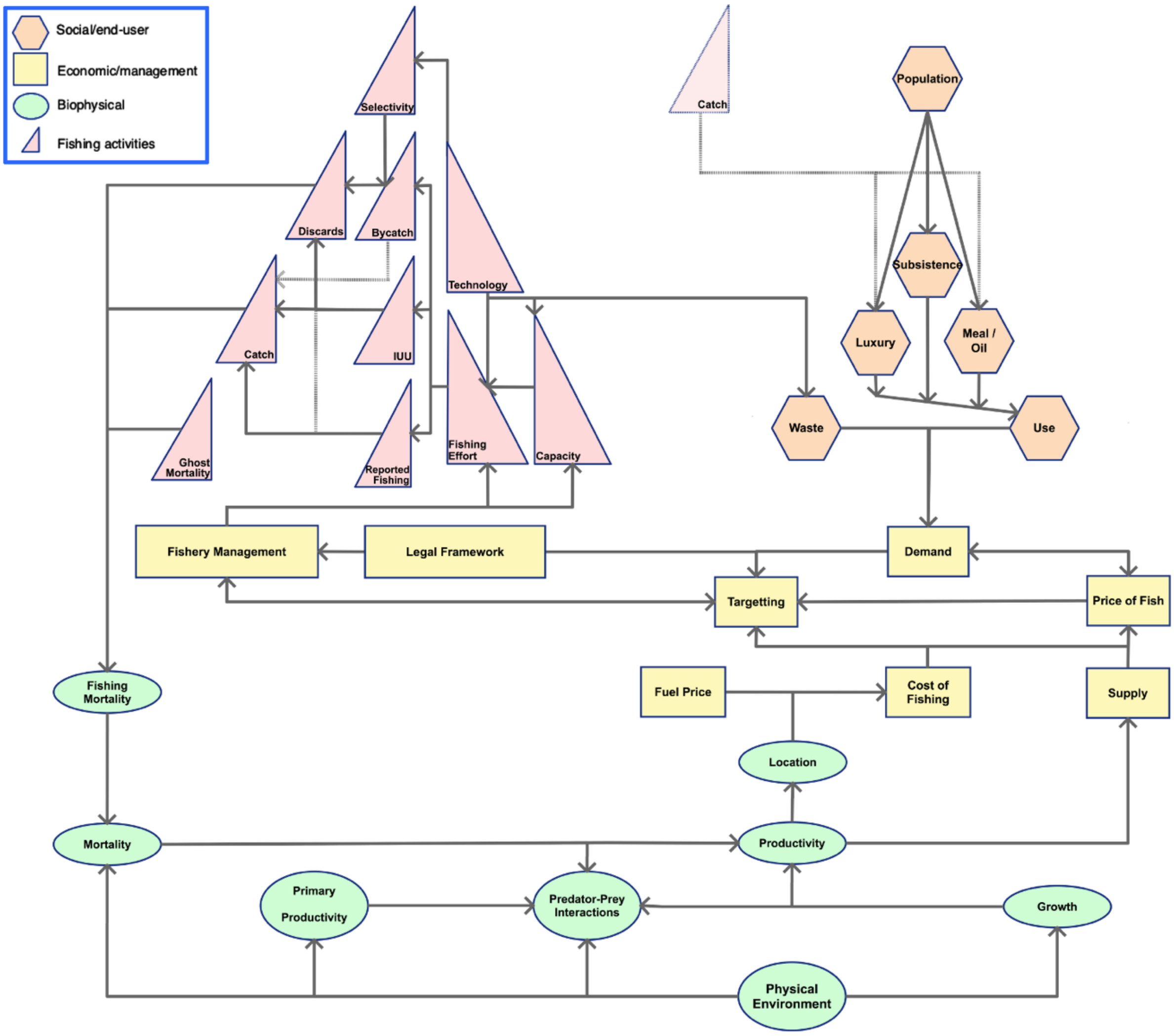


Figure 2.2. Simplified representation of parameters used in a fully integrated supply and demand model for global fisheries. Trade is not explicitly represented, although implicitly related to management, price/cost and demand.

2.2.1) Mortality from fishing.

Landings are almost exclusively used as a proxy for fishing mortality in global models (Jones et al., 2015; Thorson, Branch, Jensen, & Quinn, 2012). Landings data is widely available and for accounting and trade alone has been historically available. The data is, however, prone to high uncertainties, as it often does not account for discards and bycatch (Christensen et al., 2015; Pauly et al., 2003), illegal activities (Agnew et al., 2009; Christensen et al., 2015; FAO, 2006c, 2014b; World Bank, 2013), over and under reporting to the FAO (Watson & Pauly, 2001) or small scale fisheries. A compliance parameter linking to economic incentives has been used in place of illegal fishing in bioeconomic models (Merino et al., 2012), and a couple of studies included estimates of discards in the mortality parameter (Christensen et al., 2009; Rosenberg et al., 2014). Pauly and Zeller (Pauly & Zeller, 2016a) suggest that official landings data, and therefore the measure of fishing mortality in models, are underestimated by over 50%. This is particularly true in the small scale (artisanal) fisheries of the world, as global data collection has historically focused on the industrial and large-scale sectors, although this attitude is changing (e.g. www.toobigtoignore.net).

Fishing and environmental factors can affect organisms directly and indirectly (Travers et al., 2007), and the additive or synergistic nature of interactions need to be studied further (Blanchard et al., 2012; Perry et al., 2010). The effect of fishing on mortality through nutrient removal (Jennings et al., 2008) and across the ecosystem (Branch, 2015) is mostly unknown, which can invalidate some ecological models (Jennings et al., 2008; Jennings & Brander, 2010). It is paramount to gain accuracy in global fisheries and ecosystem models by integrating better estimates of fishing mortality and developing methods to forecast change in these rates.

This is particularly important as new approaches to fisheries are considered. For example, a change in paradigm in selectivity, so called “balanced harvesting”, has been suggested as a solution to both sustainability of global fisheries and increasing yields (Burgess, Diekert, Jacobsen, Andersen, & Gaines, 2015; Zhou, Smith, & Knudsen, 2015). This remains a controversial topic (e.g. Branch, Lobo, & Purcell, 2013; Burgess et al., 2015; Burgess, Polasky, & Tilman, 2013) as it goes against decades, if not centuries, of size and species selectivity. There is a strong need for models which integrate and compare different fishing scenarios and paradigms, estimate the relative vulnerability of co-existing species (Branch, 2015) and integrate human activities as part of the ecosystem, without simply adding a fishing mortality factor (Darimont, Fox, Bryan, & Reimchen, 2015; Hilborn et al., 2015; Mcowen, Cheung, Rykaczewski, Watson, & Wood, 2014; Perry et al., 2010; Rose et al., 2010; Travers et al., 2007).

2.2.2) Supply and demand from a human perspective.

Fleet dynamics and their drivers are often excluded from global stock assessment models (Quaas et al., 2016), or oversimplified as the “price of the catch”. Not only profits but fleet capacity, costs, quotas and days at sea impact the fishing effort (Garcia & Rosenberg, 2010; Prellezo et al., 2012). Forecasting fishing mortality, and by extension, global models for fisheries, cannot be accomplished without a deep understanding these drivers (van Putten et al., 2012). Fishing is a commodity trade, and as such harvesting and (over) capacity building are influenced by market prices (Jones et al., 2015; Pauly et al., 2003; Thébaud et al., 2014), themselves driven by the use (demand) of the catch. The demand part is often reduced to the use for fishmeal and oil and population growth. Trade is often underrepresented. On the supply side, changes in location and abundance might affect costs, global and local demand, substitutions and the global trade system (Barange et al., 2010; Sumaila, Cheung, Lam, Pauly, & Herrick, 2011), which in turns will affect the demand and targeting of particular species. The role of subsidies, affecting prices (demand) and overfishing (mortality) is underdeveloped in global models (Sumaila et al., 2014). Increasing fuel price (Sumaila, Teh, Watson, Tyedmers, & Pauly, 2008), and effort (Watson et al., 2013) might affect the price of fish resources and targeting, providing feedback for future estimates of fishing mortality.

The commercial development of multispecies harvest (Hilborn et al., 2015), reduction of waste post harvesting (FAO, 2011c), or new legal frameworks, such as the recent ban on discards in the European Union (European Commission, 2014), could drastically affect the supply and demand chain. Global models, however, often assume unchanged patterns of consumption (Merino et al., 2012). With the exception of efficiency in the transformation process for feeds (Merino et al., 2012; Mullon et al., 2009; World Bank, 2013), no consideration is given to waste in consumption.

2.2.3) The 'human feedback' effect on targeting.

Besides the supply and demand chain, the complex field of socio-economics is often excluded from stock assessments and global biological models (Quaas et al., 2016), but plays an important role in fleet dynamics through drivers such as employment, welfare, quotas, revenues, (Prellezo et al., 2012), population growth, information and technological progress, and governance (Garcia & Rosenberg, 2010). Economic theory and maximization of profits are often used to forecast demand, but they do not explain it entirely.

Social aspects are often absent in global models, introducing high uncertainty in the demand and its future (Barange et al., 2010; Fulton, Smith, et al., 2011; van Putten, Gorton, Fulton, & Thebaud, 2013; van Putten et al., 2012). The future of fisheries is not only a biological or economical problem, it will affect and be affected by social aspects and communities (Allison et al., 2009; Badjeck, Allison, Halls, & Dulvy, 2010; Barange et al., 2011). Consumer behaviour drives changing demand (Verbeke & Vackier, 2005) and directly impacts targeting, yet the majority of studies focus on increased fish-protein demand without regard for the specifics (Delgado et al., 2003; Kearney, 2010). Compliance, governance and management need to be integrated in global models, quantitatively or as scenarios. Competing behaviours and strategic theory in fisher behaviour needs further study (Thébaud et al., 2014). Similarly, social indicators are often lacking due to the complexity of representing human in natural systems (Rose et al., 2010).

From a governance perspective, future changes in availability and location will strongly impact the geopolitical map. Changes in access rights (Allison et al., 2009; Daw, Neil Adger, & Brown, 2009) have been shown to affect the targeting and pricing of the resource, but are seldom represented in models. As the lack of global models combining human and biological elements might result in communication and governance failure, balancing economic, social and ecological goals is becoming paramount (Hilborn et al., 2015; Merino et al., 2012; Murawski, 2000).

2.3) Balancing knowledge gaps and complexity in fisheries models.

Global fisheries models and methods to determine the oceans yield have come a long way since the 1960s. Development of new theories for biological modelling and improvement of supply - demand analysis in fish commodities are greatly advanced from simple extrapolation of past trends. Global models have increased their depth and scope but might at times have fallen into a complexity trap without significantly increasing accuracy. Much work is left, however, in integrating different methodologies, comparing and harmonizing parameter inputs. This is being addressed somewhat from an ecological perspective in more recent global models, although the socio-economics aspects is still often underrepresented, due to the sequential nature of development of the new modelling platforms (often beginning with the climate drivers and ecological dynamics and only then moving into the dynamics of exploitation).

Feedback effects and interconnectivity between human, economics and ecological parameters are often still lacking at the global scale. As this might result in governance failure, integrating these factors in global models is necessary. The importance of scenario-based models and its implication for sustainability of seafood production cannot be stressed enough, especially when the scientific community disagrees on current biomass and productivity. Although scaling up might not be possible due to their complexity, much could be done by learning and expanding from regional models e.g. Atlantis, OSMOSE, EwE etc (Fulton, Link, et al., 2011). The next step in fisheries modelling is to create global models that capture core E2E concepts while also being cognisant of the following gaps and biases:

- Scaling. Most models seem to enjoy a wide range of disciplinary perspectives at regional level, but expand badly, if at all, at a global scale. On the other end, global models can be very descriptive of large systems, but fail when needing to 'zoom in'. Future work needs to focus on models which can be scaled up and down, as can be seen with the use of Ecopath and EcoOcean (Christensen et al., 2015; Polovina, 1984).
- Complexity. While models have increased in complexity to cater for wider range of questions of parameters, decision makers need more "approachable" options that are readily available and timely. It is the role of a model maker to ensure their model or conclusions can be accessible by various audiences.
- Representation. Economic incentives, ecosystems, human and societal behaviour and the physical environment are all part of the global fisheries system and need to be represented in models. There is also a strong and related need for harmonization of definitions. 'Harvestable' portions, for instance, can refer to the economic, technological, preferential or biologically sustainable portion of the sea, but models are rarely precise in their definitions.
- Interconnectivity. The biological, economic and social components of models interact and need to be treated with a feedback effect on each other, not separately. Many parameters, such as mortality, depend on the various synergies between the components. Scientists cannot create models that look at fisheries from one perspective alone. Ecosystems might be in need of protection, but human populations also require marine production.
- Quantification vs. scenario. Although scenarios are useful for describing potential changes in the future, many parameters need to be appropriately quantified in order to produce predictions that can provide more resolved (and realistic) insights. For instance, levels of discards and illegal fishing need to be included in models to increase accuracy in estimates of

mortality. Management scenarios need to become mainstream, and the output of different storylines compared.

- Comparison of outputs and framework. Whenever the same question posed by different models is answered in different ways, this means either one or more models is not suited to the question, or that there is strong uncertainty, either parametric or structural, leading to varied representation of the system and any associated scenarios. While the importance of looking at the same problems with different theories cannot be underestimated, there is a strong twofold need to understand any differences in input parameters (and their implications) and to recognise where uncertainties lie.
- Transparency. Models cannot be a 'black box'. If decisions are to be made on the output of a model, its assumptions and the parameterization must be clear.

Of the main gaps common to various global fisheries yield model, three stand out, due to their focus on connecting human and ecosystem models: fishing mortality, fleet dynamics and human feedback. While models will eventually require these parameters to be explicitly determined, it is paramount to first ascertain that they are given in sufficient details to be integrated accurately.

Fishing mortality is intrinsically linked to the fishing effort and the CPUE (Maunder et al., 2006), but while there has been significant attempts to update the global fishing effort (Anticamara et al., 2011; Bell et al., 2017), the data is rarely given at the level of detail necessary to extrapolate meaningful trends. Some inconsistencies have been found in the data, such as number of vessels, engine power or effort measures vastly varying from one year to another. It is likely that these variations stem from the data sources themselves as well as the methods used to fill in the gaps. Furthermore, a common bias in fisheries literature is to underestimate the impact of the artisanal fishing sector, and instead of considering it as a separate entity, to either aggregate it with the industrial fleet in datasets (e.g. FAO), or to give it engine power and fishing effort based on those derived from the industrial fleet, introducing bad approximations. These uncertainties permeate global fishing fleet management. Scenario building and skilful models can only be built from accurate knowledge of past events. A better understanding of the global fishing fleet and its evolution is therefore necessary to reduce the uncertainty in estimates of fishing potential and futures. In particular, while industrial fishing fleets might give a great indication of the evolution of fish stocks and the environment, artisanal fleets further detail the development of the more 'human' aspects of fishing.

Modelling fisheries ultimately depends on the question at stake, which would indicate the parameters to use. However, when considering the most important questions of present and future yield, much is left to do in order to get satisfying answers. Most methods seem to have stayed inside the bubble of their own discipline, with relatively unchanged perspectives and biases. At regional level, many models and studies have tried to integrate various perspectives, but at a global level much is left to do. Many questions such as trade, global markets, access rights, food security and connection with aquaculture cannot be treated at a local level, yet few global models give answers. The parameterization is equally problematic, as many studies have kept historical biases and ignored inaccuracies leading to high variability in results. End-to-end models aim at satisfying the need for interconnectivity of the fields, but are still in their infancy, and seem to have fallen into the fallacy of complexity. The next step in their development would be a conceptual framework that will point out the different parameters requiring attention and their links.

2.4) Modelling fisheries yield: on the need to adopt transdisciplinarity to move forward.

While it is undeniable that global fisheries models have vastly evolved, it is important to state that their current form is far from final. Looking at past trends highlight some traps that we might fall into during their future developments. First and foremost, the past development of models seems to have come by wave, each time highlighting a new difficulty. The 1960s saw the first interest in the ecological components and in the limits to the carrying capacity of the oceans, which contradicted the past status quo of unlimited fisheries expansion. These models were, however, mostly static, made broad assumptions based on energy transfer and the 'harvestable portion' of the oceans. Conversely, they opened up the discussion of the uncertainty in yield estimates and highlighted how limited our knowledge of the ocean was, leading to an array of studies based on metanalysis and the explicit integration of extrapolations methods in fisheries models. The question of predictivity in models became more common in the 1980s and has since become the driving factor in recent years. These early predictions, however, were still focusing on the extrapolation of previous catch data, with sometimes a supply and demand component added to them. The 1990s and 2000s saw human activity models gaining in complexity and depth, adding management scenarios and some biological components for the supply sides, but remain largely based on simple extrapolation of past trends and disconnected from the dynamic aspect of ecosystems. At the same time, biomass models evolved to incorporate the future of the resources, although they were and remain still mostly disconnected from harvest possibilities. The suggested answer to this dual disconnect has been in the development of E2E models, but the depth and breadth of these come at the price of complexity and intense data needs.

Disconnect has become an important topic in recent years, and a trap we might have fallen into. The vast number of models has led to an equally vast number of results and estimates, giving an uncertainty of three orders of magnitudes to the oceans yield. With the renewed focus on the importance of seafood, both as nutrition, trade commodity or employment, as recently highlighted in the United Nations' Sustainable Development Goals (sustainabledevelopment.un.org), such a wide range of estimates is, at best, unhelpful. A reason for the difference can be found in the mono-disciplinary aspect of each class of models. Supply and demand models are based on economic theory, and usually ignore changes in human and ecological components, even so-called bioeconomic models.

Biomass models often only include human aspects as a static mortality factor and ignore preference in targeting. Interestingly, extrapolation of catch integrates such elements the most, as technological, preferential, cultural and marketing aspects are implicit to past data. The total lack of explanatory drivers, however, does little to raise the extrapolation models beyond (unadaptable) trendline and baseline comparison data. Human aspects are often missing or overly simplified in all types of models, with economy used as the closest proxy. While economy is an important element, governance and consumer behaviours are almost as important, but difficult, if not impossible, to integrate in models. Scenarios do not currently typically have the depth necessary to represent such changes. E2E models, in theory, aim at integrating these different aspects, but the scientific nature and data-driven complexity of these models is likely to render them inaccessible to management in more resource-limited regions. Even in more affluent areas, translation of the information into a useable form can be challenging. Furthermore, most complex models can fall into the 'black box' trap, were users who have not invested sufficient time in model understanding and skill assessment are not aware of the assumptions and caveats underpinning them.

While E2E are a good and necessary step forward, it will be some time before these models are widely used meaningfully. In a few cases, they are providing meaningful inputs to management (strategically and tactically), but this is still the minority. In parallel to this development, it is important to reconsider global fisheries yield model through a broader lens, including human components, integrated to one another. We live in a world where everything is connected, and considering feedbacks in models goes beyond a simple and often mechanistic add-on, as has been done before. Considering different disciplines has a far-reaching implication on how the problem is formulated. While ecologist have focused on the yield from the perspective of sustaining ecosystems and economists from a poverty alleviation perspective, integrating these meaningfully requires us to question what definition of sustainability we are aiming for. Trandisciplinarity has been suggested as a tool to attain sustainability goals (Hirsch Hadorn, Bradley, Pohl, Rist, & Wiesmann, 2006), but its application to fisheries yield models requires reframing the latter as a whole, and not 'gluing' components to one another. Modelers can no longer afford to myopically focus on disciplinary details or try to extrapolate from regional to international. Not only the complexity reached forbids it, but models achieved this way might not be adaptable to changing conditions.

Chapter 3 - Defining global artisanal fisheries.

Chapter 3 is a reformatting of Rousseau, Watson, Blanchard & Fulton (2019), Defining global artisanal fisheries*, (Marine Policy Vol. 108, doi.org/10.1016/j.marpol.2019.103634).*

3.1) Introduction.

Small-scale artisanal fisheries are undeniably important and remain central to issues of livelihood, human rights, employment, poverty and malnutrition (FAO, 2018). The sector represents half the world's fishing effort (Rousseau, Watson, Blanchard, & Fulton, 2019b), over one-quarter of the catch in volume (Watson & Tidd, 2018) and 90% of employment in capture fisheries (FAO, 2015d). Quantitative analysis – of status and trends and global comparisons – have a significant role to play if we want to elevate small-scale artisanal fisheries to their rightful place in the global fisheries discussion. Such efforts, however, have often been stymied to date. While there have been an extensive number of local scale (or at least constrained) studies of small-scale fisheries from a social sciences perspective, there have been far fewer large-scale quantitative analyses. In contrast with industrial fisheries, which are recognised and studied throughout the world, quantitative/comparative scientific studies on small-scale artisanal fisheries have been carried out in a limited number of research hubs, typically from the developed world (Oliveira Júnior et al., 2016), and only rarely do they attempt to encompass a global range of data, focusing instead on case by case analysis.

A significant hurdle to broader analyses is that confusion exists between the terms used (artisanal, small scale, coastal, inshore, …), which lack clear definitions in the literature. This confusion is accentuated by the variation in how different terms are used interchangeably in different countries and regions (FAO, 2015d; Sumaila, 2017). This, in turn, is reflected both in the variety of national legal frameworks and in the scientific literature, complicating comparative studies and international agreements.

Although some have suggested that a strict global definition for artisanal fisheries would be inappropriate (FAO, 2017), previous authors have argued that a definition is often required to clarify the scope and application of multilateral agreements, and lack of a clear agreed definition can lead to reduced effectiveness, such as seen in international subsidies disciplines (Sumaila, 2017). In an attempt to address the complex situation without introducing self-defeating rigidity, efforts have been made to create flexible approaches, such as the Food and Agriculture Organisation (FAO) Voluntary Guidelines (FAO, 2015d). While such flexibility does have its place, particularly in discursive considerations, more quantitative approaches require a categorisation of items in order to treat and study them (Johnson, 2006), as a lack of categorisation (definition) leads to a proliferation of uncertainties. This can be clearly seen in fisheries science, where (for example) global estimates of the proportion of artisanal in the catch have been given variously at levels from 25% (Pauly & Zeller, 2016b) to 50% (FAO, 2015d).

Specialised fisheries literature has focused on the problem of defining artisanal fishing and its consequences, but few have tried to determine its source. We suggest the problems arises from failing to see artisanal fisheries as an enterprise that transcends scientific and legislative concerns, and that a simple exercise of rhetoric and reconnecting with the meaning of each term used can explain much of the confusion.

3.2) Methodology.

In order to expose the root of the confusion, two distinct reviews of the scientific literature (section 3.3 below) and national legislations (section 3.4) have been carried out, to analyse the various methodologies and terminologies used when describing or defining 'artisanal' fishing. For each (internationally-recognised) state having access to the sea, as well as three autonomous territories, the main legal documents related to 'fishing' were collected through the databases ECOLEX and FAOLEX.

The definitions of various sectors were extracted, and classified according to their explicit titles (subsistence, coastal, small scale or artisanal) and their consistency with topographical, usage, extent, or technical elements. Effort was made to extract the text in their original language or with official translations of the law in either English, French, Spanish or Arabic. A few countries required the use of translators (e.g. Georgia), while the most literal translation of each sector was used (e.g. 'pequeña escala' in Spanish can be translated directly as 'small-scale'). Specific issues in translation are highlighted in Appendix 1.

We further compared the terms used in fishery-related laws to their historical definitions outside of the field, to unveil both similarities and discrepancies. We subsequently used an exercise of semantics based on Aristotle's rhetoric (Sloan, 2010) in order to distance ourselves from specific jargon (section 3.5). We then demonstrated that it is possible to associate the rhetoric to a quantitative framework based on available data, allowing comparative analysis of international components of the sector.

3.3) Defining artisanal fisheries in the literature.

The complexity of the definition of artisanal and small-scale fisheries is as difficult in the scientific limits itself to literature as anywhere. Published work shows various attitudes towards the sector, which we categorized as: *receptive*, *descriptive* and *decisive*[1]:

- ***Receptive*** (or acceptive) is the acknowledgement that artisanal fisheries exist and are delimited in a way, usually implied by the data or the specific fishery studied. By extension all vessels/people/industry linked to the data are in the sector (Kosamu, 2015). The focus is then not on the boundaries of the sector but on correlated aspects, such as describing the life of fishermen, or specific issues linked to the management of the fishery. Various studies have focused on poverty (Chiwaula, Witt, & Waibel, 2011), vulnerability (Chiwaula et al., 2011; Weeratunge et al., 2014), interdependences and cooperation (García-de-la-Fuente, Fernández-Vázquez, & Ramos-Carvajal, 2016; Schuhbauer, Chuenpagdee, Cheung, Greer, & Sumaila, 2017; Schuhbauer & Sumaila, 2016), well-being (Weeratunge et al., 2014), socio-environmental impact (Kittinger et al., 2013; Schuhbauer et al., 2017; Schuhbauer & Sumaila, 2016), gender equality (Kleiber, Harris, & Vincent, 2015; Weeratunge et al., 2014), etc. This approach, arguably the most common in the literature, particularly in social science and governmental/NGO reports[2], often limits itself to reviewing various examples of artisanal fisheries and their impact. While useful to understand the consequences of the sector, it lacks causal analysis and is reductive in the sense that the lack of clear defining terms rarely allows for expansion of the study. The contextuality of artisanal fisheries implies that what is applicable to one spatially distinct fishery might not be valid for another one (Schuhbauer & Sumaila, 2016).

[1] Strictly speaking, we can loosely link these terms to the rhetorical functions (description, formal definition and process/semi-formal definition) described in Trimble (1985), *English for Science and Technology: A Discourse Approach*, Cambridge: Cambridge University Press, pp. 180.
[2] We refer the reader to the extensive literature from the global partnership “Too Big to IGNORE” (toobigtoignore.net) as an example of both receptive and descriptive approach to small scale fisheries.

- ***Descriptive*** goes beyond receptive by not only acknowledging the existence of artisanal fisheries, but also by listing their parameters, in practice defining the sector by its most common features. This method is often used to justify the differences in the impacts between sectors, based on their intrinsic characteristics, and is very common when analysing socioeconomics or environmental characteristics of various fisheries and behavioural or self-determinative attributes of the fishers (Naranjo-Madrigal, van Putten, & Norman-López, 2015; Rees, Rodwell, Searle, & Bell, 2013; Ünal & Franquesa, 2010). It is exemplified in the FAO guidelines (FAO, 2015d), which encourage flexibility in the definition of the sector while focusing on its sustainability. While allowing for a comparative analysis of various fisheries, it highlights the fact that artisanal fisheries, with very different components, might have very different impacts, and often restricts itself to geographic areas of similar socio-cultural backgrounds (Rousseau, Watson, Blanchard & Fulton, 2019b).

- ***Decisive*** describes an attitude whereby a (relatively) clear distinction between what is and is not artisanal is parametrised with quantifiable criteria. A cut-off point, more often than not related to technical parameters such as the length of the boat (e.g. 12m according to EU law), is used when the study needs to compare or describe various fisheries which would otherwise have little in common. As no agreed global definition of artisanal fisheries exist, studies have used a variety of cutting methods:
    - By exclusion, such as considering artisanal fisheries are all that is not censused or which does not use specific gears (Kaufman, 1962; Leiva, Busuttil, Darmanin, & Camilleri, 1998). This method historically highlighted the focus of studies on the industrial/large-scale sector and the lack of knowledge on the artisanal/small-scale fisheries.
    - By single or multi-field criteria, whether they be technical/vessel-based such as length, gear or engine power (Allison & Ellis, 2001; Davies, Williams, Carpenter, & Stewart, 2018; Ruttan, Sumaila, & Pauly, 2000), or economic such as number of employees (Reubens, 1947), end-use

of the catch, such as consumption and/or non-commercial (Zeller, Booth, Pakhomov, Swartz, & Pauly, 2011), total catch (value or volume), spatial (depth or location) or fishing effort. The method allows for comparison across countries but presents the disadvantage of aggregating sub-sectors of very different styles together and then comparing the 'incomparable', in very general terms, such as via fishing power, economic or social background and environmental impact. Conversely, in the European Union, where a unified definition of 12m allows for comparability, it has been shown that vessels of 15-16m length, technically industrial, behave like the small-scale coastal fleet (IFREMER (coord.), 2007).

- By comparison, often of a social, communitarian, developmental or cultural nature. When comparing across regions with limited data, the method allows for characteristics of the artisanal sector of (often) a country to be inferred from neighbouring/similar countries, such as Norwegian artisanal fisheries considered under 12m, as per EU law (Rousseau, Watson, Blanchard & Fulton, 2019b). The focus of these papers is often less on the definition of the sector itself than its implications.

As each of these approaches has its own advantages and drawbacks, each analysis tends to use the method most adapted to the fishery being studied, which often limits its expansion to global studies. It is also common to define a sector by referring to another (perhaps more understood) sector, such as artisanal being small scale and commercial (Zeller, Harper, Zylich, & Pauly, 2015).

The complexity of clearly defining a sector is accentuated by the implications of whatever adjective is used to refer to them (Emmerson, 1980), though recent methods have tried to move beyond single-field criteria. The semantic problem of using particular terms and considering them interchangeable adds another level of complexity, as shown in the global legal framework (section 3.4).

The use of structural and functional descriptors (García-Flórez et al., 2014) or vessel, economic and social features (Gibson & Sumaila, 2017) allow for a 'grading' of the sectors. While such approaches can scale globally, they are extremely data-intensive, and no attempt has yet been made to expand them beyond the regional level. Using too stringent criteria can further complicate studies, as data availability varies, and sometimes forces authors to use different criteria for different regions such as effort vs catch data (Teh & Pauly, 2018) or using specific technical-based definitions for each countries according to their laws (Rousseau, Watson, Blanchard & Fulton, 2019b).

3.4) Sectorial definitions found in legislation.

Besides the consideration of what defines artisanal fisheries, the semantics of the term present a dual problem. Firstly, *fisheries* are not a simple concept. While *fishing* is the relatively simplistic harvesting action carried by the *fisher*, *fishery* is a complex construct, a "bio-tecnico-socio-economic system" (G. L. Kesteven, 1973). In recent years, the term 'métier' has been used to try and define clearly some technical aspects of the fishery, although its meaning has evolved over the last few decades[3], and diverged from the origin of the term[4], leading to further confusion where it should have brought

[3] Strictly speaking, a 'métier' referred in the 1970s to both the fishing gear (and target species) and the concept of skills and knowledge required to practice fishing, especially in the context of the seasonality, time frame of the action of fishing (Jorion, 1979), linking both technical and social elements to the biology. In recent years, the meaning of the word in fisheries science and law has gone away from the social and focused on the technical, such as the definition used in European law : "a group of fishing operations targeting a similar (assemblage of) species, using similar gear, during the same period of the year and/or within the same area and which are characterised by a similar exploitation pattern" (Decision 2008/949/EC). The word 'fishery', on the other hand, while it can focus on specific species and gears/vessel types (particularly in developed countries), can still be used with an inclusion of economic, social and community components.

[4] Up until the 19th century at least, the word 'métier' has been used in French almost exclusively to refer to a trade (profession) (de Roquefort, 1829), with the 'petits métiers' (lit. 'small trade') referring first to unskilled labour (servants, porters, wagoners,…) (Thoumas-Schapira, 1955) later taking on the meaning of traditional, artisanal, and small scale work. In fisheries, 'petits métiers' became a reference to coastal, manual fishing, as opposed to trawlers (Krier, 1956) and to the 'grand métier' (lit. 'large trade'), the nickname given to Cod fishing off Newfoundland (Recher, 1977). 'Petits métiers' is still used the Mediterranean fleet to refer to vessels who do not possess "a trawling or tuna-sardines licence" (Reyes, Bahuchet, & Wahiche, 2015).

clarity. Scientific literature can refer to either term depending on the scope of the study, but legislation and policy usually focus on either the fishing or the fisher, and as such the use of the term fishery or métier in a national legislative context could be perceived as over-generalizing and confusing. Secondly, as with scientific literature, numerous adjectives can be found in legal documents referring to 'artisanal' fisheries (such as 'small-scale', 'coastal', 'inshore', 'traditional', 'social', 'customary', 'subsistence', …), but not only does the meaning of each adjective vary with the country, there is no consensus on overlap between the terms.

Progress may be possible if we compare the use of the various concepts and their meanings outside of the field of fisheries:

- *Artisanal* has a specific definition in industry or craft, based on the process and technology involved (Ostrom, 1980; UNESCO, UNCTAD, & WTO, 1997), itself linked to the idea of 'primitive' craftmanship (Lewis, 1961). Therefore, there is a concept of technique, process and technology, with a focus on the process rather than mass production of the produce. We will thus compare the use of the word *artisanal* with the *technical* aspects (gear, boat, engine, …).
- *Scaling* is generally agreed to be the size of the enterprise, a clear, numerical representation of its *extent*.
- *Coastal* is equally meaningful, a representation of the distance to the shoreline, depth and geographic limitations. The word has therefore a clear *topographical* connotation.
- *Subsistence* is, however, relatively tricky. The concept mirrors the idea of survival dependent on the product. Though there is no clear demarcation of what one can do with the products to be considered subsistence (in the case of fisheries, direct consumption, barter, low value sale, …), the focus is a limit on the *use* and the *goal* of the catch.

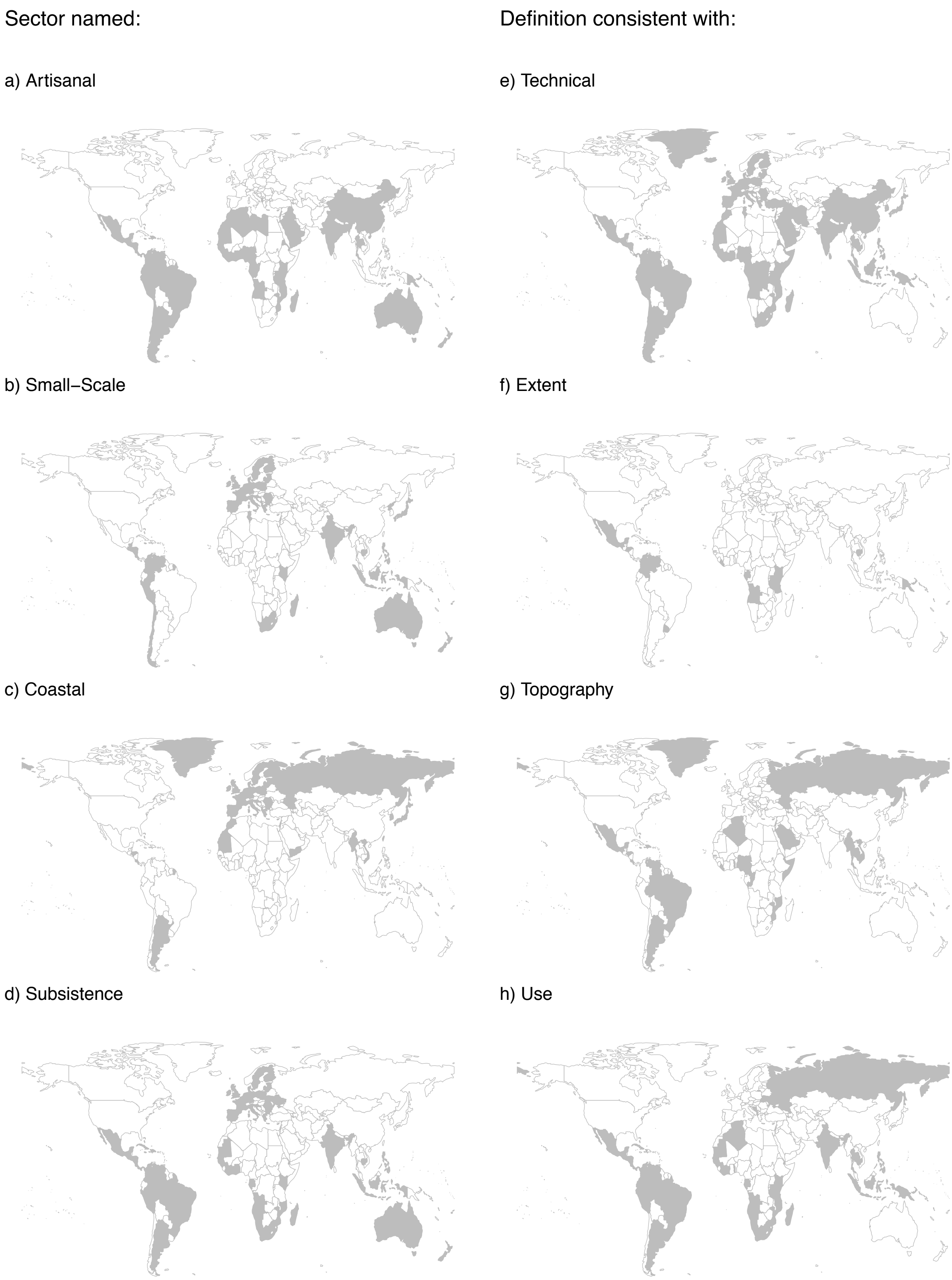


Figure 3.1. Countries naming sectors as 'artisanal' (a), 'small-scale' (b), 'coastal' (c), 'subsistence' (d) in their legislative framework, compared with the content of the definition classified as 'technical' (e), 'extent' (f), 'topography' (g), and 'use' (h). Countries in white do not refer to the term, the European Union is considered under the umbrella of Regulations 508/2014 and 2015/523. Only the principal name of the sector (and synonyms if specified) are used (i.e. if a sector named 'artisanal' is described as 'small-scale' in a law, the name was classified as 'artisanal' and the definition consistent with 'extent'.

We can compare the use of a specific term in legal texts (left column, Fig. 3.1) with its above-defined meaning (right column, Fig. 3.1). Some clear geographical patterns can be seen in the consistency (or lack of) between the use of a term and its meaning. The use of the words 'artisanal' and 'subsistence' to define sectors is consistent with 'technical' and 'usage' aspects. In fact, the few countries for which there is not a clear link between the two columns are the ones referring to the terms in their laws but without any definition. While they could be defined further in policies or guidelines, at the very least the use of the word indicates the recognition of the existence of such sectors in other countries, if not (necessarily) recognised nationally (e.g. the European Union). Furthermore, few countries limit the technical aspects of fishing or its end use without referring to them as 'artisanal' or 'subsistence'. The 'recreational' sector, referred to by over 80% of the countries considered, presents a further challenge, as it might include some aspect of subsistence[5].

The term 'coastal' is often clearly understood as topography although many countries impose a distance limit on a sector without naming it 'coastal'. An important exception to the consistency of 'artisanal' and 'coastal' with 'technical' and 'topography' is found in the legal texts of the European Union: while Regulation 508/2014 names the sector as 'coastal', the definition is consistent with 'technical' aspects, therefore understood as 'artisanal' in our framework. The meaning of small-scale fishing, on the other hand, seems very misconstrued. Few countries refer to the extent of the activity, either from an economic, social or environmental perspective. In fact, the vast majority of 'small-scale' sectors is consistent with a technical definition and should be re-labelled 'artisanal'.

A difference between Latin-speaking countries (here limited to Spanish, Portuguese and French) and English speaking countries has been noted (García-Flórez et al., 2014), with the former assumed to prefer the use of 'artisanal', and the latter 'small scale'. Indeed, over 78% of Latin speaking countries use the name 'artisanal' compared to 50% of the English-speaking world, with similar

[5] The EU Regulation 2015/523 for instance, refers to "recreational" as being "non-commercial", and seems to exclude subsistence by restricting to sport and entertainment. The Barbados Fisheries Act, on the other hand, clearly includes "personal consumption" in the sport fishing sector.

proportions of legislations consistent with ‘technical’ aspects (Table 3.1). The preferred use of ‘small-scale’ sector in English speaking countries, however, is in fact less common than assumed, with only 29% (and under 16% consistent with ‘extent’). The term ‘coastal’ is only used in less than a fifth of countries in both linguistic regions (10 and 17% respectively), although definitions using ‘topographical’ elements are found more than twice as often (29 and 34% respectively). ‘Subsistence’ is widely used as a sector name in both the English-speaking world (over 46% of countries), and Latin-speaking (over 70%), relatively consistent with a ‘usage’-based definition (33 and 66% respectively). Interestingly, in the Arab World, relatively low levels of terminology are found, due to a sizeable proportion (38%) of relevant legislation that does not separate fishing into, or by, sectors; nonetheless ‘artisanal’ is still used in 48% of the Arab-speaking countries.

Table 3.1. Number of countries using the terms ‘artisanal’, ‘coastal’, ‘small-scale’, ‘subsistence’ in their legislative framework, by main spoken language. Countries might be double counted (esp. Latin languages) due to countries with more than one official language. Although the Latin family consists of many more languages, we kept it to the three main languages spread through colonisation. ‘Unreferred’ indicates that none of the above-mentioned names are found in the legislation (although other names such as ‘traditional’ or ‘customary’ might be found).

Main language	Countries	Unreferred	Name: Artisanal	Defined: Technical	Name: Coastal	Defined: Topography	Name: Subsistence	Defined: Use	Name: Small-scale	Defined: Extent
Arabic	21	8	10	9	3	4	2	3	1	0
English	52	12	26	24	5	15	24	17	15	8
French	21	3	15	15	3	6	12	11	3	3
Spanish	18	0	16	15	4	6	15	15	10	6
Portuguese	9	0	8	9	1	4	8	7	2	1
Latin language (Spanish/Portuguese/French)	47	3	37	37	8	16	33	31	15	10
Total, World	154	22	73	100	42	40	76	56	54	18

3.5) For a rhetorical approach.

While the problem of defining ‘artisanal fisheries’ in scientific literature is one limited by both the aim and usefulness of the term, legal documents might stay away from a clear definition ‘on purpose’, as the law can be constructed with the intent to interpret a sector name as its ‘*ordinary meaning’* (Solan & Gales, 2016). This approach, however, can be messy when extended to international agreements[6], as the difficulty of defining ‘artisanal fisheries’ has been shown to exist in the use of language itself. Indeed, each country has their own definitions, which have changed over time[7], and with various association with other terms (‘traditional artisan’, ‘small industry artisan’, …). With fishery being a transdisciplinary[8] field, and international agreements needing to overcome the language barrier, the confusion resulting from the use (and misuse) of specific terms such as artisan, small scale or subsistence has proliferated. To overcome this issue, we want to address what we think is the root of the problem, i.e. the incorrect use of the terminology.

The use of ‘artisanal’ is complex, because the word itself is multi-layered and a potential confusion is unrecognised. Two specific aspects of the term need to be considered: the understandable but undefined meaning of the term in fisheries, which we aim to address, and the definition outside of the field of fisheries, akin to ‘technical and skilled’ as mentioned above. For the

[6] “A treaty shall be interpreted in good faith in accordance with the ordinary meaning to be given to the terms of the treaty in their context and in the light of its object and purpose”. Vienna Convention of the law of treaties, 1969 (EIF 1980), Sec. 3, Article 31.1

[7] A striking example can be found in the Chilean Legislation, where the limit between artisanal and industrial sector has increased from 15 Gross Registered Ton (GRT) in the 1980s (Decree 175/1980 regulating fishing activities) to 18m, 80 cubic metres and 50 GRT since 2007 (Law 20.187 of 2007).

[8] While the concept of a single discipline (‘disciplinary‘) is something that is relatively well understood, the distinct concepts of pluri, multi or transdisciplinarity often require clarification. In this study, we understand transdisciplinarity as being a framework that requires systemic inputs from many disciplines of various scopes and levels of coordination (including beyond traditional academic disciplines to include stakeholders and practitioners), in order to rephrase and refine the problem at hand, or as we described earlier: ‘transcending disciplinary concerns’. We refer the reader to the work of Manfred Max-Neef (Max-Neef, 2005) for further details and in-depth discussion on the matter.

sake of clarity, our use of the word ‘artisanal’ hereafter is limited to the former, while the latter will be referred to as ‘technical’.

Since the question of the definition of ‘artisanal fishing’ is one of rhetoric, we deconstruct the term with the help of the rhetorical tool of Aristotle, the ‘circumstances’, best known as the ‘6Ws questions’ (Sloan, 2010): The ***What*** refers to the fishing action itself, and encompasses what is affected by it, here the species. The ***Where*** has been defined previously as the location and topographical components of the fishing action. The ***Why*** is understood as the purpose of fishing. Nowadays we consider whether the action of fishing is for enjoyment (recreational), feeding the fisher and/or his family (subsistence), for a product that can be exchanged for other goods (barter) or sold (commercial). The cultural aspect can also be included in this (fishing for religious ceremony for instance). The ***How*** can be somewhat confusing, as it can refer to either the technical aspect of the action or the (descriptive) manner in which it took place. The technical component is the easiest to grasp, linking in fisheries science to the tools, vessels and gears. The manner is subtler, as it implies a certain judgement on the action. While not as qualitative as the how-tool, it is very relevant to fishing, as it can be linked to the concepts of impact, inclusiveness, equality, and sustainability. The two meanings are linked, as the choice of the tool will have a strong impact on the manner in which the fishing takes place. The ‘how’, both tools and manner, can also be linked to what the literature refers to as ‘scale’, i.e. a construction of methods, extent and impact. The ***When*** is even more subtle. While Aristotle meant it as the ‘time’ (here, relevant to seasonal or day/night time of fishing), there is an implied link to the past. This could be interpreted as the historical aspect of fishing, often understood as ‘customary’ or ‘traditional’. The final circumstance may be, counter-intuitively, the most difficult, but also most important aspect of artisanal fishing: The ***Who***, or actors. Akin to recent discussions on native inhabitants[9], the who ties up with the concept of self-determination and recognition by the community, and the right to fish, which are arguably the hardest to quantify.

It is clear that most of these concepts link to each other in their implications for fishing (Table 3.2). It is, for instance, impossible to untie the species targeted (what) from the gear used to catch them (how), their location (where) and availability (when), the access rights (who) and the end use (why). The answer to these aspects, in fact, defines what the fishery itself is. Like multi-criteria analysis and the concept of artisanal fishing itself, flexibility in the interpretation and rigorous application are necessary (Fig. 3.2). Our suggested method is similar in principle to the multi-disciplinary multi-criteria one suggested by Gibson and Sumaila (Gibson & Sumaila, 2017) for 'small-scaleness', but presents the advantages of being simpler and expandable to national fishing fleets as well as specific fisheries. Its implementation is akin to the descriptive methods (see above), in the sense that it does not attempt to set any of the criteria (although it is possible to do so in this framework) but allows for direct comparison between fisheries and/or national fishing sectors. It presents the further advantage of not being limited in its application or scope to a single discipline, but to use concepts and proxies which allow for disciplinary overlap.

In the proof-of-concept example below (Fig 3.2], the national fleet of six countries was described using the parameters and proxies described [Table 3.2] (and classified relative to each other (normalised 0 to 1, with values and chosen extremum outlined in Appendix 2). This is a simple example to demonstrate the method rather than aiming to be comprehensive or exhaustive. Under the proxies employed here, it is clear that Indonesian fisheries are 'more artisanal' than the other countries. By contrast, the European countries considered (France, UK and Iceland), although over 80% artisanal (assuming the definition of the European Union applies, even to Iceland), show comparatively lower

[9] Please refer, for instance, to the ongoing debate about the concepts of self-determination, proven link and community-recognition of the Australian Aboriginals, e.g. http://www.dpac.tas.gov.au/divisions/csr/oaa/eligibility_policy

Table 3.2. Aristotle's circumstances (6Ws) applied to fishing, with example proxies chosen to establish estimates for national fleets in Figure 3.2.

6 Ws	Name	parameters	Could also be?	Example of proxy chosen as example in Fig. 3.2	Source
What	Targetting	Species involved.	When	% of catch (in tonnage) from tuna/anchovies*	seaaroundus.com***
Where	Location	Geography	When	% of catch (in tonnage) in EEZ of the country	seaaroundus.com***
		Distance to shore		NA (implied in EEZ)	-
		Depth		NA (implied in EEZ)	-
Why	Purpose	Recreational / Subsistence / Barter / Commercial / Cultural	Who	% of catch (in tonnage) for subsistence	seaaroundus.com***
How	Means	Vessel characteristics		Average Gross Tonnage per vessel*	EU fleet register (1), statice.is, produce.gob.pe***
		Gear		% of fleet not trawl	EU fleet register (1), statice.is, produce.gob.pe***
		Motorization		Average Engine Power (kW) per vessel*	EU fleet register (1), statice.is, produce.gob.pe***
		Investment	Who	Subsidies per capita (Thousands US dollar)*	(2)
	Impact	Societal impact	Who	% of agriculture/fisheries to GDP	World bank data***
		Environmental impact		% of threatened species in the commercial fisheries*	fishbase.de***
		Extent	What	% of commercial species to total species	fishbase.de***
When	Seasonality	Day/night time fishing		NA - not relevant at national level	-
		Seasonal species/ground	What	NA - not relevant at national level	-
	Historical	Traditional/Customary	Who/Why	% of indigenous to national population**	iwgia.org***
Who	Actor	Self determination		% of persons employed in fisheries/agriculture to national population**	(3)
		Recognition (community)	When	NA - not relevant at national level	-

(1) http://ec.europa.eu/fisheries/fleet/index.cfm
(2) Sumaila et al. (2010). A bottom-up re-estimation of global fisheries subsidies. DOI: 10.1007/s10818-010-9091-8
(3) FAO (1999). Number of fishers. FAO Fishing circular FIDI/C929 (Rev.2)

* lower values considered higher level of artisanal
** population data from world bank https://data.worldbank.org/
*** all fleet, catch and employment data for 2014, species 2018, indigenous data 2018, population data of various year corresponding to measured data

levels of 'artisanal-ness'. Specifically, while the targeting parameter (here limited to tuna and herring/anchovies) and gearing is similar to the poorer countries, unsurprisingly other technical (vessel size, motorization), economic (investment, subsidies) and geographic parameters are more advanced. In fact, besides the lack of subsistence fishing in the UK, French and British national fishing sectors look identical relative to other countries. An important message here, however, is that looking at more than one parameter is paramount when comparing various artisanal sectors. If, for instance, only gear was considered, all countries would be at the same levels of 'artisanal-ness', while considering all factors it is clear that the sectors are extremely varied. While this simple example no doubt contains many uncertainties, as a proof of concept it does show that sufficient information exists to allow for comparisons between countries (in turn allowing for the analysis of broader patterns) if an attempt is made to use clearly laid out criteria when classifying fisheries and fleets.

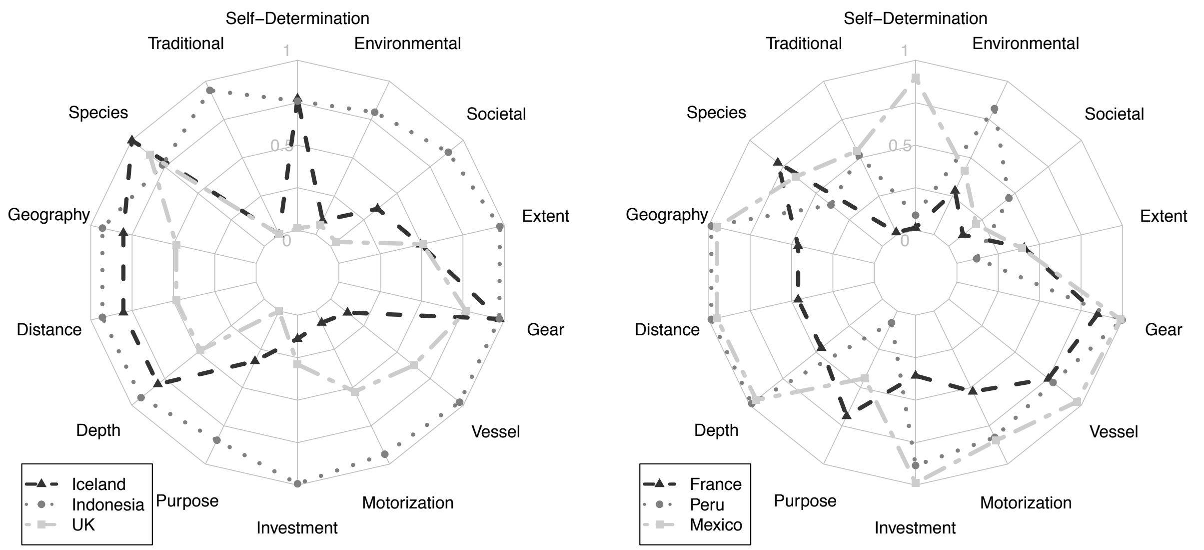


Figure 3.2. Graphic representation of indicative parameters used to describe artisanal fisheries, comparing the national level of 'artisanalness' in Iceland, Indonesia and the UK (left) and France, Peru and Mexico (right). The parameters of depth, distance and geography use the same proxy. Community recognition and daytime/seasonal fishing were excluded from the parametrisation, as they were assumed to be of low significance at the national level. Sources of the example proxies used for quantification are provided in the supplementary material. All values were normalized (to 1) via comparison with the maximum for the proxy (see Appendix 2).

3.6) Conclusion.

There has been substantial discussion about how to best define artisanal fisheries. Here, we have clarified a few important points. Firstly, no single method is best to define or describe artisanal fisheries, it is case-specific and depends on the specific goals of classification. Some methods such as the theoretical framework we proposed, however, can be applied to many different case studies and allow for direct comparison between various fisheries. By extension, it could be used as the basis for developing policy and legal agreements between regions and countries by recognising the variation in the sector and which parameters to focus on.

Secondly, the language has been and remains extremely important. Not only is the use of sector names over others dependent on the language of the country, but the meaning of each name has been in many cases confused and has lost much of its original intent. Clarification is required if clear international, multi-language agreements are to be reached. The artisanal sector cannot easily be included and protected in legal agreements if not properly defined. From the science and research perspective, the development of consistent, global databases for employment, vessels characteristics and catch are heavily dependent on the definition used for artisanal sectors. Studies cannot be expected to aggregate or compare data that are substantially different in nature. Given the undoubted importance of the sector, not only socially, but economically and ecologically, it is important that a consistent means of referring to it must be found. Multilateral agreements would benefit from universally accepted definitions (Sumaila, 2017), particularly in zones of conflict due to access rights and sectorial quotas. Given the baggage of existing terms there is a temptation to suggest that using a different word than small-scale, artisanal, etc. might be best. However, there would no doubt be resistance to the introduction of a new word, thus standardising the use of the term 'artisanal' (with its implications and subtleties) might be preferable.

Finally, while (at least) adopting guidelines to refer to the artisanal sector is important, policy makers should keep in mind that these sectors are extremely adaptive, and what is considered industrial today might be seen as artisanal tomorrow, while the artisanal of today could have disappeared. The latter point is particularly well illustrated by the slow but steady disappearance of the unmotorized fishing fleet across the globe. These shifts are also symptomatic of the fact that the duality of artisanal-industrial is not necessarily helpful (R. L. Kaufman, Hodson, & Fligstein, 1981). Fishing sectors are continuums (Defeo & Castilla, 2005), and trying to clearly delimit them as two separate entities can be futile and painful exercise. The authors recognise that in a topic area as complicated as this one, with so many competing research foci around artisanal fisheries that flexibility is, by far, the best approach. Nevertheless, definitions based on multiple criteria are best when there is a necessity to define sectors in legal or management frameworks, or to allow for comparable studies. It is this ultimate need to create definitions that allow for comparability across scales and for an assessment of the true magnitude of these forms of fishing globally that has driven us into contemplating the issue. Our experience highlights that the complexity of the question of defining artisanal fisheries can be broken down into simpler, more comparable arguments. In turn, we have attempted to answer the need for a flexible -yet simple- framework for tackling such a complicated issue, and to place it against a transdisciplinary background, hopefully opening up discussions for approaches that can be applied globally.

Chapter 4 - Evolution of the global fishing fleet, its impact and management.

Chapter 4 is a reformatting of Rousseau, Watson, Blanchard & Fulton (2019), Evolution of global marine fishing fleets and the response of fished resources *(Proceedings of the National Academy of Sciences of the United States of America, June 18, 2019 116 (25) 12238-12243, doi.org/10.1073/pnas.1820344116) and its* supplementary material.

4.1) Introduction.

Marine fisheries support global food security (FAO, 2018) , human livelihood and employment (Barange et al., 2011), as well as global trade (Bellmann, Tipping, & Sumaila, 2015), and will continue to do so in the foreseeable future with the benefit of wise management. Understanding fishing capacity is paramount to its management (van Hoof, 2010) and failure to manage fisheries compromises all the services these vital resources offer. Although the importance of knowledge of fish stocks is undeniable, it cannot be disassociated from the fishing processes themselves. Catch per unit of effort (CPUE) is still a widely used measure of the well-being of a fished stock (Maunder et al., 2006), which cannot be estimated without some measure of the fishing capacity, defined hereafter in its simplest form - the number of existing fishing boats. While there has been significant work to collect global fishing fleet data, most notably by the United Nation's Food and Agriculture Organization (FAO), gaps in the data are non-trivial, and no satisfying method has been found that fills them and allows for comparison or prediction without major and often flawed assumptions (Bell et al., 2017).

Although progress has been made toward reconstructing the historical size and power of the global fishing fleet (Anticamara et al., 2011; Bell et al., 2017), several inconsistencies are apparent in the results. This is partially because public records aggregate disparate fishing fleets into one component as if they were easily interchangeable units. It is, however, well understood that global fishing fleets consist of at least two separable components: 'artisanal' and 'industrial', the former comprising both motorized and unmotorized elements. These components of the fleet, although interacting, are different in their scope and aims (Plagányi et al., 2013), and vary vastly in their regional definitions. The industrial fleets are better documented and reported than artisanal fleets (Zeller & Pauly, 2018), specifically how they developed to exploit often distant fish stocks, which could not be fished efficiently by artisanal fishers. Recent technological progress, particularly in electronic monitoring systems, has provided a substantial volume of information on the composition and behaviour of the larger components of the industrial fleet (Kroodsma et al., 2018). In contrast, the extent and impact of the artisanal fishing fleet is underestimated in the literature. This paper aims to strengthen the knowledge of the global marine fishing fleets by reconstructing the number and engine power of artisanal and industrial fishing vessels.

For centuries, fishing vessels used sails and oars as propulsion methods. The introduction of steam-powered trawlers and the subsequent improvements in propulsion had a dramatic effect on the efficiency of fishing vessels, their spatial reach, and on landings; perhaps best documented in the Northern Atlantic (Tyedmers, Watson, & Pauly, 2005). While the focus nowadays is on industrial fishing operations, a vast portion of global fishing still occurs at artisanal levels (Pauly & Zeller, 2016a; Watson & Tidd, 2018). Further, as the research on fisheries is biased towards the developed world, the impact of the unpowered artisanal fishing fleet is often overlooked in academic studies. As up to a quarter of fishing vessels are unmotorized globally (FAO, 2018), neglecting this component of the fleet and its transition through technological advances results in vast underestimates of the impact of fishing, particularly in the poorest parts of the world. Improved understanding of the motorization of the fishing fleet and taking a step back from focusing almost exclusively on detailed, industrial fleets are fundamental for both reconstructing the past, and for predicting the future evolution of fishing fleets. In this paper, we compiled data from various sources to fill in the gaps in the knowledge of global marine fishing fleets, particularly their history and level of motorization, the separation to artisanal (both motorized and unmotorized, referred hereafter as “powered-artisanal” and “unpowered-artisanal”) and industrial sectors, and their fishing effort.

4.2) Methodology.

The marine fishing fleet data from 149 sovereign states, along with Taiwan, Greenland the Faroe Islands was collected. National and international databases were used, along with official (governmental) literature and any scientific or grey literature providing either the number or engine power of fishing vessels. Fishing fleet data was separated into three sectors: unpowered-artisanal, powered-artisanal and industrial vessels, using either data-specific or legal definitions of artisanal fishing. The number of vessels in each sector and country was interpolated with a (double) sigmoidal fit. An ARIMA model was then used to extrapolate to 1950 and/or 2015, whenever necessary. For missing data on unpowered-artisanal fleet, it was assumed that the subsector increased proportionally with population (Teh & Sumaila, 2013) before a threshold based on GDP and decreased thereafter at rate similar to the observed increase in powered fleets.

Both motorized sectors were divided into classes of engine power, each with a yearly ratio to the total number of vessels and a mean power per vessel (PPV). The ratios and PPVs of countries with sufficient data was determined with generalized additive models. The average engine power of vessels in countries with limited or no data was reconstructed by comparing to ‘similar countries’.

Days at sea (Anticamara et al., 2011) were used to estimate nominal fishing effort per country, year, engine power class and sector. The effective effort was calculated using a 2.6% increase per annum in technological efficiency (creep), relative to 1950. Independent landings data (Watson, Kitchingman, Gelchu, & Pauly, 2004; Watson & Tidd, 2018) was used to calculate the CPUE. Detailed information on data sourcing and analysis can be found in Appendixes 3 and 4.

4.2.1) Data sourcing.

The data sources include various databases from the Food and Agriculture Organization of the United Nations (FAO, n.d.-d, n.d.-b, n.d.-c), Southeast Asian Fisheries Development Center (SEAFDEC, n.d.) and the European Union (EU) Community Fishing Fleet Register (European Commission, n.d.). These databases have various strengths and weaknesses. In particular, the vessels are not necessarily separated meaningfully between fishing sectors, and some include inland/freshwaters fisheries, particularly for the FAO data. Whenever possible, the time series for the number of vessels was reconstructed initially with other sources, and the FAO databases were used as validation. The average engine power given in the FAO database was considered applicable when the discrepancy between the number of vessels in the database and the reconstructed value was less than 50%. Some data points contain typos (e.g. a digit doubled or a ‘0’ added at the end, however, only obvious ones were corrected). Please refer to Appendix 4 for the sources used.

4.2.2) Data pre-processing.

Caveat: All data, no matter the source and its credibility and depth, has its own flaws and uncertainties. Censuses are the most accurate, unbiased and complete sources of data, but were very rare. National registers were an invaluable source of information and were the most widely used. One must, however, carefully consider their scope. It is not uncommon for national registers to ignore vessels under a certain size from registration. An extreme example of this is the Australian General register of ships (www.amsa.gov.au), which grants exemption to any vessel under 24m and is not fishing on the high seas. This is significant as the largest portion of country fishing fleets is commonly under 24m (e.g. EU fleet). When compared to the last complete documentation of the Australian fleets in the 1980s, this suggests that the AMSA data only captured 20-30% of vessels. In this case, however, it is important to note that, given the substantial restructuring of the fleet since then (due to a vessel buyback scheme) and the commercialization of the fleet, the AMSA numbers are, however, likely to be reflective of the active vessels.

Even the European Register of Vessels, arguably the most extensive database of vessels in both number and depth of information, shows merely a snapshot of the European fleet. The database was developed through the 90s, and as such, vessels destroyed or retired prior to the consolidation of the register might be absent. Most of the data for the earlier years should thus be considered with caution, as probably it is likely underestimated. The disaggregation between small-scale and industrial sectors was furthermore subject to interpretation. While all vessels over 12m of length in the Register are considered industrial, ‘towed vessels’ under 12m are, by law, industrial as well. As a vast extend of vessels are equipped with more than one gear type, this leaves the absolute numbers of small-scale (thereafter artisanal) and industrial vessels estimated in this study to debate.

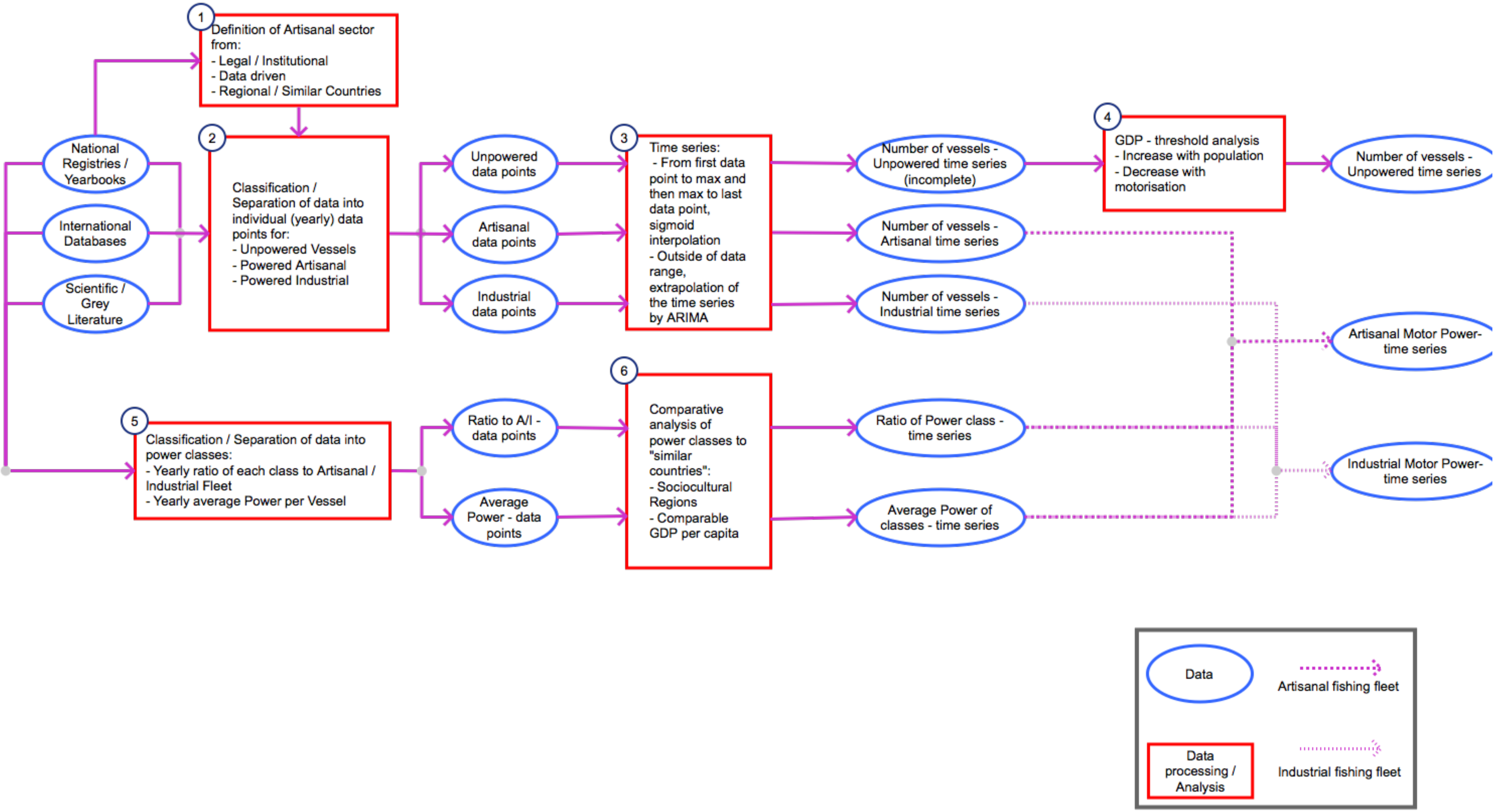
Our study has tried to avoid these issues by widely sourcing information. Expanding data sources, however, has its drawbacks, such as dealing with contradictions, which were often more difficult to tackle than missing figures. As the artisanal sector (both powered and unpowered) is often underreported, or even erratically omitted entirely, it is not uncommon for reported numbers to fluctuate widely from one year to another. Furthermore, it is a challenge to judge the objectivity of some countries in their reporting, due to their own potential political agendas, and unfortunately even external observers can have their own biases. A major source of information for the Soviet fishing fleet comes from the USA's National Oceanic and Atmospheric Administration (NOAA) or declassified CIA reports, but these will have a strong focus towards the largest aspects of the industrial fleet.

Some key countries, particularly in South East Asia and Sub-Saharan Africa, possess a vast inland fleet, which is often difficult to separate from the marine one (1) and might lead to inflated estimates. The separation of the fleet into the three sectors we analysed and our exclusive focus on marine fisheries reduced fluctuations in data but also restricted the availability of usable data. A careful balance and the understanding on the mechanism and scope of reporting was often necessary. For instance, countries practicing artisanal fishing transshipping to a 'Mother' boat (support vessel) introduced a challenge. Most boats (except the 'Mother' vessel itself) will be artisanal in their fishing operations, while their coordination with the support vessel can produce a large scale operation (Aiken, Andre Kong, Smikle, Mahon, & Appeldoorn, 1999). We made the choice to consider this association as artisanal by focusing on the individual vessels rather than the scale of the operation or the destination of the catch.

In the pre-processing explanations, the term 'artisanal' refers to its powered segment, and unpowered/unmotorized fleet to the 'unpowered-artisanal'. Each process in Appendix 4 corresponds to a data source as given in Appendix 3. Additionally, the following processes were used for the definition of artisanal:

- <u>From data</u>: no separation in artisanal, industrial or unpowered (artisanal) was required, as the data source detailed the number of vessels separately. Data given this way will always prevail over the country legal or institutional definition of what constitute an artisanal fishing vessel, as it will most likely be consistent throughout the years.

- <u>Decision:</u> whenever a legal definition of artisanal fisheries could not be applied, we used a 'similar' country based on regional demographics (in parenthesis). This includes:



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1238 **Figure 4.1. Conceptual diagram of the processes used to separate the fishing vessel/engine power data into time series and interpolate/extrapolate.**

1239

- China and Taiwan. Both legal definitions are too stringent, leading to almost no industrial and almost no artisanal respectively. We used <10GT as definition instead, based on ‘similar countries’ Korea and Japan.
- Norway: No clear definition of artisanal fishing is given in the law, so we used the EU guidelines instead (<12m and no towed gears).

- Given by data: Using the legal definition for artisanal fisheries, the data was already directly disaggregated in such a way that didn’t require further processing (e.g. EU database, all vessels are categorized by length and gear so application of the EU definition of small-scale fisheries was straight forward). This was the case in regions where the cut off between sectors is given by technical specificities of the vessels (tonnage engine, gear, length) and the data given as such.

4.2.3) Conversion of data in time series and interpolation / extrapolation of the number of vessels and engine power.

The following processes were used to extrapolate the number of vessels and their respective engine power (Fig. 4.1), the numbering (removing the prefix ‘4.2.3.’) corresponds to the explanations bellow:

4.2.3.1) Definition of artisanal fisheries.

We did not assume any difference between the terms “artisanal”, “small scale”, “subsistence” and regrouped them thereafter under the umbrella term “artisanal”. Whenever possible, we used the institutional definition of artisanal fisheries (i.e. as defined by a fisheries law, or as used by the main fisheries data collection agency). As our study focused on the nature of the fishing boat, and many countries define artisanal fisheries by the distance to the shore, the type of catch or the type of fishery, we used only the institutional definitions were the characteristics of the artisanal boat were explicitly defined (e.g. “less than 30 GT” or “outboard pirogues”) and the data allowed for separation. In some cases, the data itself made the distinction, i.e. reports of the number of artisanal and industrial vessels. When this occurred, the data was used instead of using the institutional definition. Whenever the distinction between the sectors was not clear cut, or the definition was impractical (e.g. the definition of the artisanal sectors in China and Taiwan meant almost no industrial and artisanal, respectively), the definition of neighbouring countries was used (e.g. <12m for some European countries, as per the European Union, or Tuna fisheries in the Pacific Islands). A list of the definitions used for artisanal fishing vessels can be found in the Appendix 3. We further separated the artisanal sector into two components, powered and unpowered. Anecdotally, only Taiwan legally considers any motorized vessel to be industrial (see comment above).

4.2.3.2) Separation of the data by sector.

Although most data could be separated directly into the three sectors (unpowered-artisanal, powered-artisanal and industrial) based on the data, motorization levels and the country definitions of artisanal fishing, some data points gave only a total number of vessels (e.g. FAO 2011; FAO 2013; FAO 2015) or an aggregate that did not correspond to the definition. In these instances, the data was either separated into various classes (length, GT, power etc.) based on the appropriate definition of artisanal fisheries or a ratio was applied based on other data points. A description of the specific processes used to separate the three sectors into separate data entries is provided in Appendixes 3 and 4. The disaggregation by sectors was important to our study but is highly dependent on their definition; however, as we largely followed the common practice of using national definitions, most of the grey area in the distinctions was avoided or at least externalized.

4.2.3.3) Interpolation and extrapolation of the data in time series from 1950 to 2015.

For each country and sector (unpowered and powered artisanal, industrial), the year of first data, last data and maximum were extracted. From the first year of data to the year of the maximum number of vessels and then from the year of the maximum to the last year of data, the data was converted to a logistic scale with the formula:

$$LS = \frac{NV - Nmin}{Nmax - Nmin} \quad (1)$$

with:

LS the number of vessels given on a logistic scale from 0-1, 0 and 1 corresponding to the respective asymptotic minimum and maximum of vessels for the time frame considered.

N_{min} the minimum asymptote, corresponding to the minimum number of vessels predicted by the model (often 0).

N_{max} the maximum asymptote, corresponding to the maximum number of vessels predicted by the model (akin to a carrying capacity of the sector)

NV the number of vessels as given by the data.

The logistic fit was constructed under R using the packages glm (R Core Team, 2017) with a quasibinomial fit between the logistic scale and the year. The variables Nmin and Nmax were estimated by successive iteration of the fit and interpolation by minimizing the mean error between the data values and the fit. Missing data between the year of first data and year of last data was interpolated using this fit. In countries with a reported collapse or where the destruction of the fishing fleet had occurred, due to civil war (e.g. Independence of Timor-Leste from Indonesia), collapse of the fishery (e.g. anchoveta in Peru) or natural catastrophe (e.g. 1991-92 cyclones in Samoa), the time series was split into further segments for interpolation.

From 1950 to the year of the first data and from the year of last data to 2015, the number of vessels was modelled, if necessary, using Autoregressive Integrated Moving Average (ARIMA) from the auto.arima() function (Hyndman & Khandakar, 2008) and extrapolated with the predict() function of R. The ARIMA was chosen to recognize the increasing uncertainty of a fleet-based time series when predicting results beyond a few years, unlike our estimates of sigmoid fits, more adapted to create the shape of the fit than estimate projections. Due to the number of ARIMA models necessary to recreate hundreds of time series, the auto.arima() function was favoured, to allow for automation, simplicity and consistency of results. No seasonality was considered in the models. The error on the forecasting was given as the 80% confidence interval of the fit.

While ARIMA-based forward forecasting was limited to relatively short times, a few countries required extensive (i.e. >5 years) backward forecasting, leading to high uncertainty. It is important to note, however, that for the vast majority of these countries the number of vessels was low (<10), and the high relative uncertainty translated to low absolute error. See Appendix 5 for details of number of points estimated this way.

4.2.3.4) Further extrapolation for the unpowered fleets.

The non-motorized (unpowered-artisanal) fleet of 57 countries was reconstructed using the same above methods as the powered fleet. The remaining countries, however, did not present sufficient data for the reconstruction. The unpowered fishing fleet was assumed to follow an increase proportional to the increase in population (a simplified version of the assumption employed in previous studies (Teh & Sumaila, 2013) to estimate the coastal population and number of fishers), up to a threshold year, after which time it stabilized to a plateau before being phased out (replaced by motorized vessels). The plateau was defined as the number of vessels exceeding 90% of the maximum recorded number of unpowered vessels for the country. The first year of the plateau was called thereafter the 'threshold year'.

Of the 57 countries with sufficient data to reconstruct the unpowered fleet, the number that reached their peak fleet prior to 1950, during 1950-2015 or have yet to split was estimated to be 15-28-14 respectively. 10 out of the 15 countries that reached their peak prior to 1950 were in the high or medium-high categories of GDP per capita (as defined below), while three of the others can be explained by 'colonization' by a rich state (Ukraine by the USSR, Algeria by France and Jamaica by the UK). Of the 14 countries which did not reach their peak unmotorized fleet in 2015, 9 were in the low or medium-low categories, and four were in the medium one. We hypothesized a link between the economy of a country and the motorization of their fishing fleet. This was confirmed as a weak linear correlation (Fig. 4.2) by plotting the year of the peak unmotorized fleet against the GDP per capita at the peak of 18 countries which reached peak fleet between 1952 and 2013 (Taiwan was excluded due to lack of harmonized GDP data, others because the peak was reached too close to 1950 or 2015 to be meaningful). The average length of the plateau (number of unmotorized vessels $\geq$ 90% of the peak number) was 12 years.

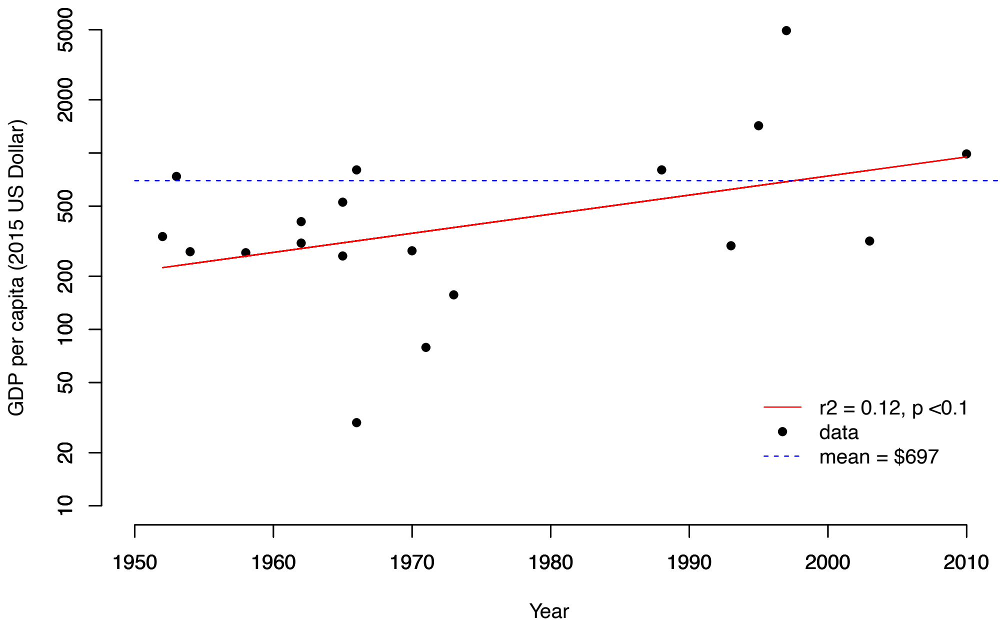

Figure 4.2. Gross Domestic Product (GDP) per capita at year of peak unmotorized fleet for 18 countries which maximized their unpowered fishing fleet between 1950 and 2015. GDP per capita expressed in 2015 US Dollar.

We used this preliminary analysis to approximate the year at which each country would reach their peak unmotorized fleet and the threshold year. For every country that did not present enough data, the unmotorized fleet was reconstructed as increasing proportionally to population (as given by World Bank data) prior to the threshold year and decreasing at the same rate of motorization (increase) after the plateau. A handful of countries, mostly in the Arabic Peninsula, did not present any data at all for the unmotorized fleet, and were removed from the analysis).

What is considered an unpowered vessel in reports can be ill-defined, ranging from anything from a hand-carved pirogue to large sailing vessels. These are very rarely subject to registration, leading to underestimates. A few censuses and studies allow for a better appraisal, but they in turn are often limited in temporal scope. To circumvent these issues, it has been assumed in this study that the growth in the size of the unpowered fleet follows that of national populations but decreases with the transition to motorized fleets. While logically sound, this approach presents two major weaknesses. Firstly, even though the number of subsistence fishers will have an effect on the number of sailing boats and pirogues, the number of fishers might not increase proportionally with the population of a country. Furthermore, no distinction was given in this study between a one-man pirogue and a 10-man sailing vessel, and nothing has been done to quantify the transition from one to another. Secondly, the replacement of unmotorized vessels by powered ones has been assumed a 1:1 ratio, based on limited data from Asian countries. Little information is available to confirm that this pattern is valid for the rest of the world, nor that the motorization happened at the same rate throughout history.

4.2.3.5) Separation of the power data in power classes.

Each data point for which engine power was available was classified as either powered-artisanal or industrial (based on previously referred definitions), and were allocated one of 10 ‘power classes’ (engine power of less than 10, 25, 50, 100, 200, 500,1000,2000, 5000kW or >5000kW) along with a “ratio” of the number of vessels in each class to the total powered-artisanal/industrial. Specific data sources for the engine power and processes used to determine the power (e.g. when a conversion is required) can be found in Appendixes 3 and 4.

4.2.3.6) Comparative analysis of the engine power - Model creation and validation.

Both average engine power per vessel (PPV) and ratio of power classes to the total number of vessels were allowed to vary from 1950 to 2015. For each power class, 3 categories of data and reconstruction models for both ratio and PPV were considered:

a) If enough data points were available (> 5 data points with at least one prior to 1960 and one past 2000), the time series (PPV or ratio) was reconstructed through a Generalized Additive Model (GAM).
b) If only a few data points were available, a comparative subset of data from ‘similar countries’ (as defined thereafter) was created, for which the average time series of either ratio or PPV was calculated. The time series of the reconstructed data was assumed to evolve proportionally to the time series of the comparative subset.
c) If no data was available, the time series of the missing power class/country data was assumed to be the average of the equivalent time series from the comparative subset of ‘similar countries’

4.2.4) Defining ‘similar countries’.

This study was in very limited circumstances based on the idea of “similar fishing countries”, which is meant to be countries whose fisheries have known close technological development. While the number of vessels in the fishing fleet of a country was extrapolated directly from available studies and data (see above), the concept of ‘similar countries’ was used solely to determine the average engine power of data-poor countries or to find the most practical definition of what artisanal fisheries are, when a legal one could not be found (e.g. similar to EU law in EEA countries, pirogues and other unmechanized boats in Sub Saharan Africa, …).

We based the expansion of the concept on two distinct parameters: sociocultural background and economy, which provided a different approach than the concept of “Bray–Curtis least dissimilar countries” used in prior studies (Bell et al., 2017), focusing less on the ecological parameters and more closely adapted to the (geographic and economic) aspects of fishing fleets:

- Sociocultural parameter. It was assumed that fisheries which belong to a group of countries of same geographic location, cultural background, language, history, … will share more vessel specificities than others. For instance, vessels used in fisheries in the Gambia are assumed to have more in common with the ones used in Senegal than the ones used in Mexico. The 14 Sociocultural regions considered for the analysis (Fig. 4.3) are grouped in the results in 10 in the results

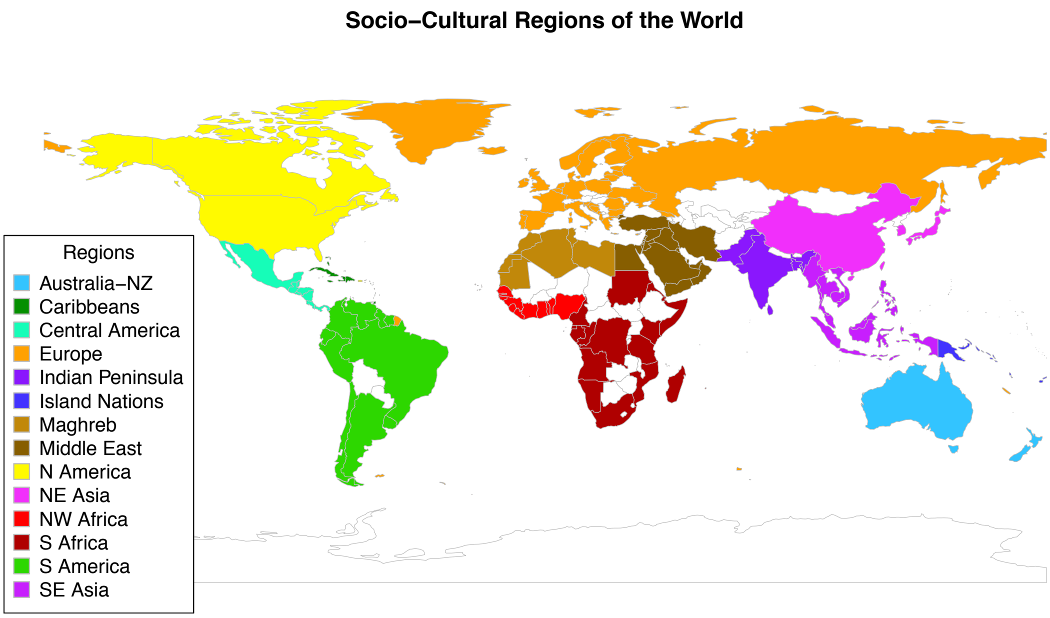

Figure 4.3. Countries with access to the high seas separated in sociocultural regions. Overseas territories and dependencies were reattached to their mother country.

- Economy. The purchasing power parity Gross Domestic Product (GDP, in 2016 dollars) per capita was chosen as a proxy for the economic level of a country and collected from the World Bank (data.worldbank.org), supplemented by the CIA (www.cia.gov/library/publications/the-world-factbook/). Each country was given a level (from 5, high to low) based on the average GDP per capita after 1995, the geopolitical map having changed only marginally since (Fig. 4.4).

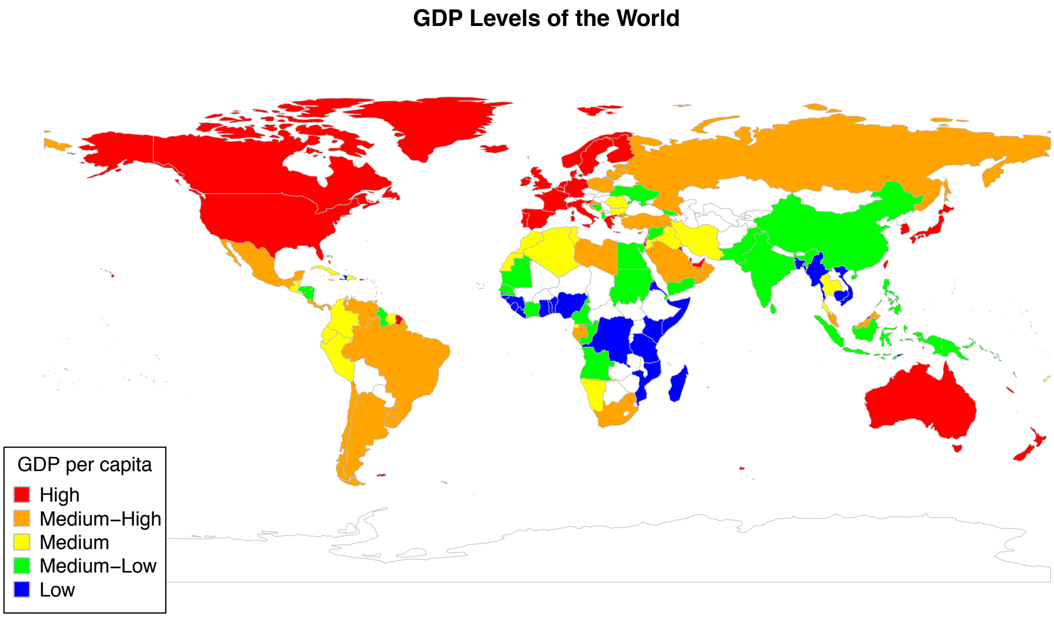

Figure 4.4. Average level of the Gross Domestic Product (GDP) per capita of the world's countries with access to the high seas. Overseas territories and dependencies were reattached to their mother country.

4.2.5) Validation of Reconstruction.

To estimate the validity of models b and c as reconstruction tools and the concept of 'similar countries' as a replacement for a Bray-Curtis analysis, we applied the models to a subset of 32 countries (incl. EU, China, Japan, Korea, Southeast Asian countries, USA) for which both the ratio of each power class and the PPV per class was known. For each country of this subset successively (with the others used as calibration dataset), 16 variations of the models b and c above were reconstructed, considering that:

- The available data consisted of only one point in either 1960, 1980 or 2000 (model b) or no data was available (model c)
- The comparative dataset was restricted successively to countries with either similar GDP or sociocultural region, both or neither.

- Artisanal and Industrial datasets were considered separately (i.e. only data specific to a sector was used to compare the average engine power of said sector).

For each of these 16 models, the reconstructed data of the 32 countries was aggregated and compared to the original dataset (Fig. 4.5). The least squares of each model reconstruction (compared to the original data) was calculated (Table 4.1).

While it was obvious that estimating a country through this method is much more accurate when at least one data point is present, some limitations were present. First and foremost, only a fraction of the world's fleet could be used as calibration, as complete datasets are scarce, and each country needed to have at least one "similar country" of both GDP per capita and sociocultural region. This leads to the subset being biased towards specific regions (Europe and South East Asia) and GDP levels (data was insufficient for the poorest countries). This in turn might have affected the results of the model comparison by limiting the number of countries each model was able to use.

Secondly, one could have expected the order of the definitions to have stayed the same regardless of the availability of data points (Table 4.1). It is not the case, as the performance of GDP only was best for the powered-artisanal sector, while Region + GDP performed better for industrial. Overall, having either one parameter or the other was consistently better than comparing to the world average. This lack of clear difference between the performances of models with GDP or Region (one parameter or both), however, can be explained by comparing the Sociocultural regions and the locations of GDP levels (Fig. 4.3 and 4.4). Much similarities can be found between the two maps, explaining the seemingly interchangeability of the parameters. If one can doubt the usefulness of comparing to both the GDP per capita and the sociocultural region, it was clear, however, that comparing countries from one group or another was more accurate than comparing them to the whole world, and by extension, to the European fleet, as done is previous studies. Importantly, the year of the data points used for reconstruction had a great effect on the overall error. The models performed best for powered-artisanal fisheries with earlier data points (1960) while the industrial performed best with data from 1980 (Fig 4.5a-b). This could be linked to the various pace at which motorization and industrialization occurred around the globe or indicate the technology transfer between regions occurring from the 1980s onwards. When no data was available, the models performed poorly, although using countries with the same GDP per capita reduced the error in estimating the ratio and engine power of the different power classes (Fig. 4.5d).

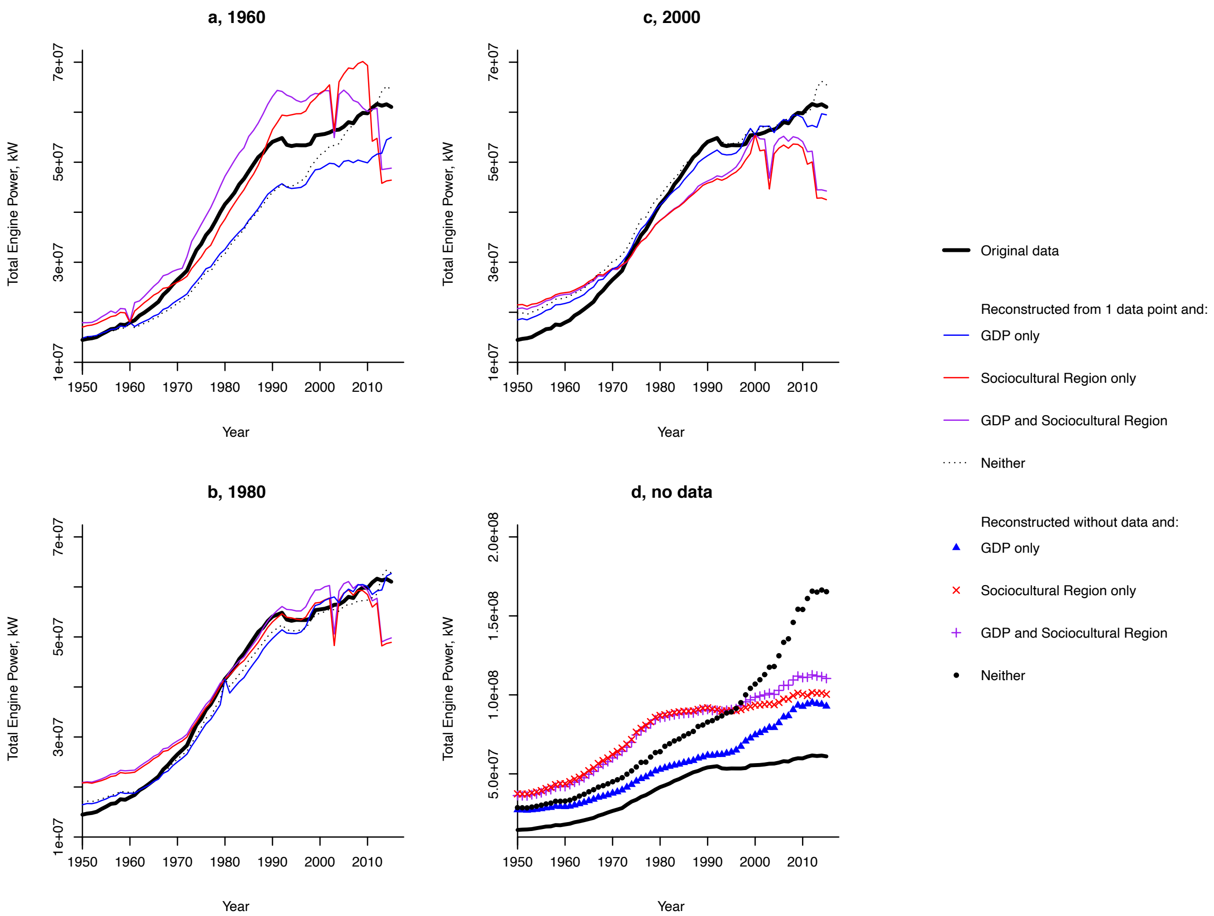

Figure 4.5. Comparison of the total estimated engine power between original engine power data and reconstruction from models using one data point of engine power taken in 1960 (a), 1980 (b), 2000 (c) or without use of data (d). The comparative 'similar countries' subsets used in the models were chosen successively as the data subsets from countries with both the same sociocultural region and the same per capita GDP category, one of these parameters, or neither. See in text comparative analysis for details.

Table 4.1. Order (from top to bottom) of the best fitted models of ratio and average engine power considered, by comparative 'similar countries' subset and parameters (GDP/Sociocultural region) used, depending on the availability of data source. "Some" data refers to at least one data point used in the models, of average year inside the range given by "year of data".

		Some data						No data	
Year of data		<1970		1970-1990		>1995		-	
Sector		Artisanal	Industrial	Artisanal	Industrial	Artisanal	Industrial	Artisanal	Industrial
Order of best fit	**1**	GDP only	Region and GDP	GDP only	Region only	Region and GDP	Region and GDP	GDP only	Region only
	2	Any	Region only	Region only	Region and GDP	Region only	GDP only	Any	GDP only
	3	Region and GDP	GDP only	Region and GDP	GDP only	GDP only	Region only	Region and GDP	Region and GDP
	4	Region only	Any	Any	Any	Any	Any	Region only	Any

Thirdly, as the definition of artisanal fishing vessels varied by country, using a comparative approach to determine the engine power of countries with different thresholds (for engine power, gross tonnage) led to increased uncertainties. This is particularly true in Sub Saharan and Pacific Island countries where engine power data was often missing. We argue, however, that comparing countries inside this so-called socioeconomic grouping is preferable to extrapolating missing data directly from European fleets, amongst the richest and most advanced in the world, as it has been carried out in previous studies.

4.2.6) Effort and catch per unit of effort.

The following method was used to estimate the number of days at sea, nominal and effective effort, based on a modified methodology previously described (Anticamara et al., 2011; Watson et al., 2013).

4.2.6.1) Days at sea.

The number of days at sea (DAS) for each country was sourced from work by Anticamara et al. (2011) and aggregated by country and engine power class, regardless of gear. While it is commonly accepted that the number of DAS is linked to the gear, we found the lack of variability in the values of combined gear/DAS suspect (Fig. 4.6) and preferred a separation by power class, allowing for much more country-specific variability (Fig. 4.7). It was implied that larger vessels would have specific gears (trawls and purse seines, longlines for tuna) and therefore specific values of DAS.

For each combined country-power class category, the DAS between year of first and last data was interpolated using GAM, and extrapolated to 1950/2015 using the average of the first/last 5 years of data. Whenever data was lacking for a power class, the average DAS of the power classes bellow and above (for the same country) was used. Missing DAS for countries without data was considered as the average of 'similar countries' value. Sources did not provide with any data for unmotorized vessels, we gave this fleet segment the same value that the lowest power class (1-10kW).

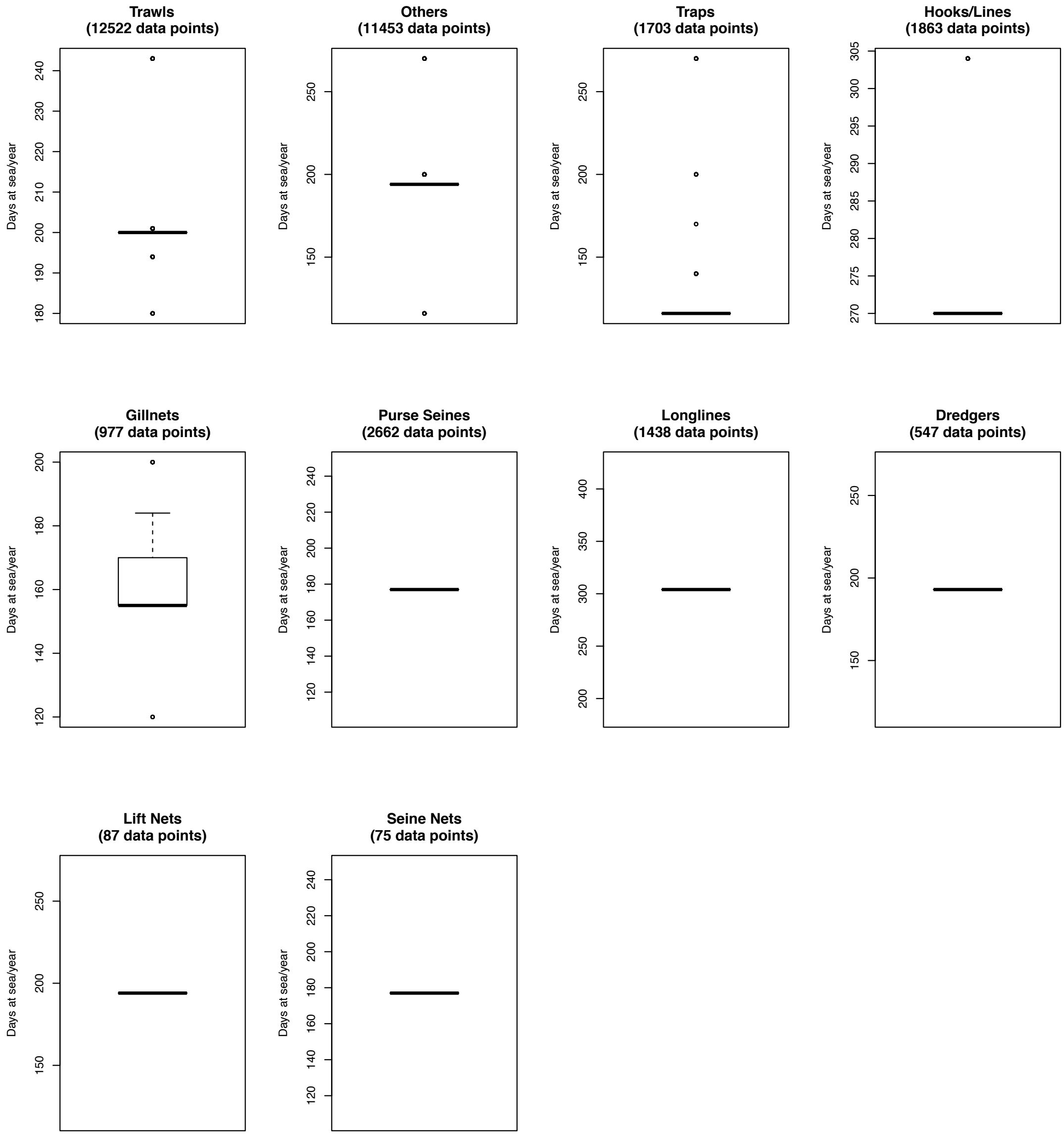

Figure 4.6. Average number of days at sea per year by gear type. Data source (Anticamara et al., 2011)**.**

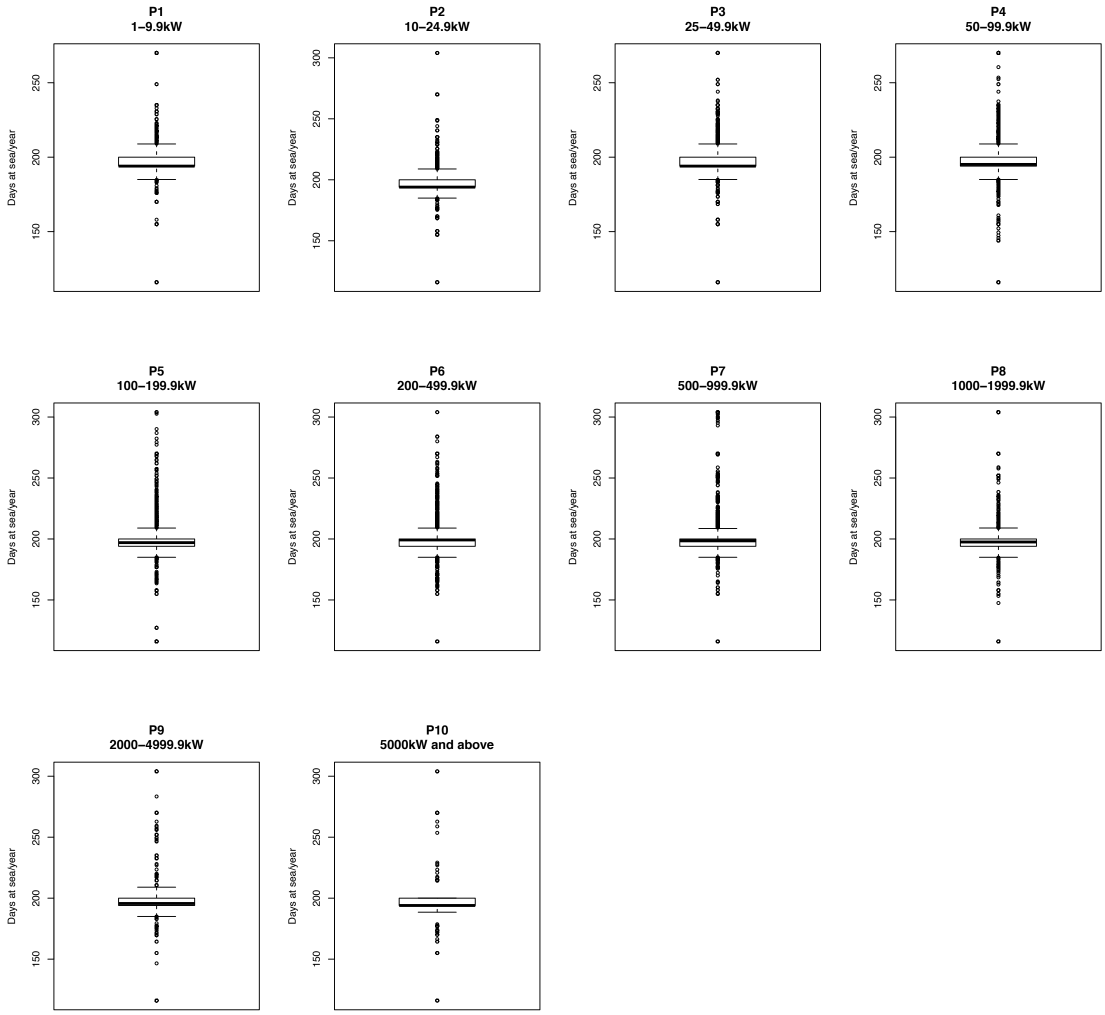

Figure 4.7. Average number of days at sea per year by engine power class. Data source (Anticamara et al., 2011)**.**

4.2.6.2) Nominal effort.

The nominal effort (in kW•Days•Year^{-1}) for each fleet segment (engine power class) was simply calculated as:

$$Effort_{Nom.} = \ Total\ engine\ power(kW) \bullet Days\ at\ sea \ \ (2)$$

As, per definition, the unpowered-artisanal fleet does not engine power, we gave a 'kW equivalent' value to the unpowered segment of the fleet (P(0)), for each country and year, equal to half the engine power of the smallest segment (Power class P(1), 1-10kW), with uncertainty ranging 0-1 x value:

$$P(0)_{eq.} = \frac{P(1)}{2} \pm \frac{P(1)}{2} \quad (3)$$

While the high uncertainty contributed to the error in the effort and catch per unit of effort, particularly in the 50s and 60s, the overall effect of the unpowered fleet on the indexed CPUE was found to be minimal, with the exception of the Asian fleet, where a vast number of unpowered vessels have historically greatly affected the marine catch (Fig. 4.8 and 4.9).

4.2.6.3) Effective effort.

The Effective effort was calculated as

$$Effort_{eff.} = Effort_{Nom} \bullet C \quad (4)$$

where C represents the technological creep.

Previous studies have used a value of 2.42% (Watson et al., 2013) based on the empirical formula:

$$C_{(\%, year^{-1})} = 20.46 \bullet Y^{-0.4927} \quad (5)$$

with C (%, year) the yearly technological creep

and Y the length of the study,

by Pauly and Palomares (Pauly & Deng Palomares, 2010). Using data from two metastudies (Eigaard, Marchal, Gislason, & Rijnsdorp, 2014; Pauly & Deng Palomares, 2010) we refined this formula as

$$\ln(C) = a \bullet \ln(Y) + b \quad (6a)$$

a = -0.45 (1 sd within [-0.28,-0.61])

b = 2.85 (1 sd within [2.40,3.42])

$r^2 = 0.20$, $P < 0.01$

or

$$C_{(\%, year^{-1})} = 17.26 \bullet Y^{-0.4518} \ (6b),$$

corresponding to a technological creep of 2.61% $year^{-1}$ (additive), 1sd within [1.32,5.18].

The effective effort with technological creep relative to 1950 was thus calculated as

$$Effort_{eff}. = Effort_{Nom} \bullet \ 1.0261^{n} \ (7)$$

with n the difference in between the year considered and 1950.

It is important to note, however, that data sourced from the above-mentioned publications dealt almost exclusively with developed, western countries. Only one of the studies researched the Northwest Mexican Herring Fishery (RUIZ-LUNA, JACOB-CERVANTES, & ESPARZA-HARO, 1997), and methods to calculate the creep were varied. It was impossible to establish any regional variations due to the lack of global data on the matter. As such, the uncertainty on the creep was vast, and translated to the CPUE (Fig. 4.8 and 4.9). A more recent publication (Galbraith et al., 2017) has explored the effect of 2, 5 and 8% creep, and chose an overall value of 5% for its model, considering previous estimates of 2.4% to be conservative. We would point out, however, that the study suffered from the same developed-world, uniform bias than its precursors. It is important to note that our one-standard-deviation estimates encompass both the deemed-conservative and chosen values.

One cannot stress enough the importance of the uncertainty on the creep. Over a 65-year period, a 1-sd uncertainty on the creep implies that the increase in fishing efficiency might have been as low as 2-fold and as high as 26-fold. In particular, although no difference was found between industrial and (powered) artisanal fisheries in the meta-studies referred, it is important to note that artisanal fisheries in developed countries do not represent artisanal fisheries of the developing world (if only because the former are almost entirely motorized, while the latter remain heavily unpowered), and as such it is unknown whether the technological creep in the poorest countries matches this value. More work is needed in this area, with a focus on the developing world and (powered and unpowered) artisanal fisheries.

Another source of uncertainty is the inclusion or exclusion of the increase in engine power in the technological creep. While its definition should exclude advances in motor development and solely represent vessel design, gear efficiency and location devices, many studies use a variation in CPUE to estimate the creep, implicitly considering an increase in engine power in its calculation. As our study considered the development of the global engine power separately from the creep, we followed estimates independent from engine power.

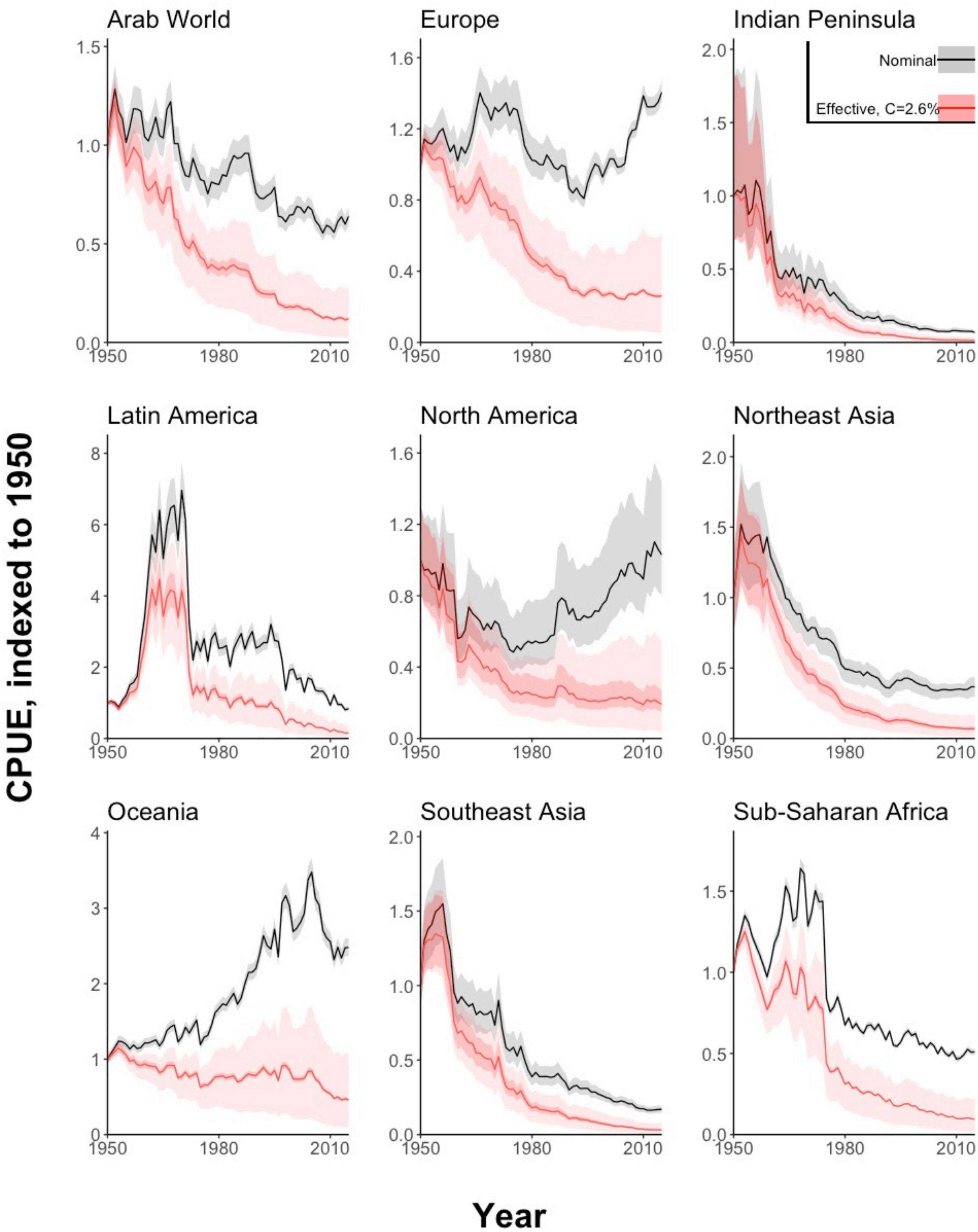

Figure 4.8. Catch per unit of effort, nominal (black) and effective (red) for various regions of the world, excluding the unpowered fleet, indexed to 1950. Grey and dark pink shaded areas correspond to a one standard deviation error (68 % confidence interval) based on the uncertainty of the engine power alone, light pink shaded area corresponds to a one standard deviation error based on the uncertainty of the engine power and technological creep combined.

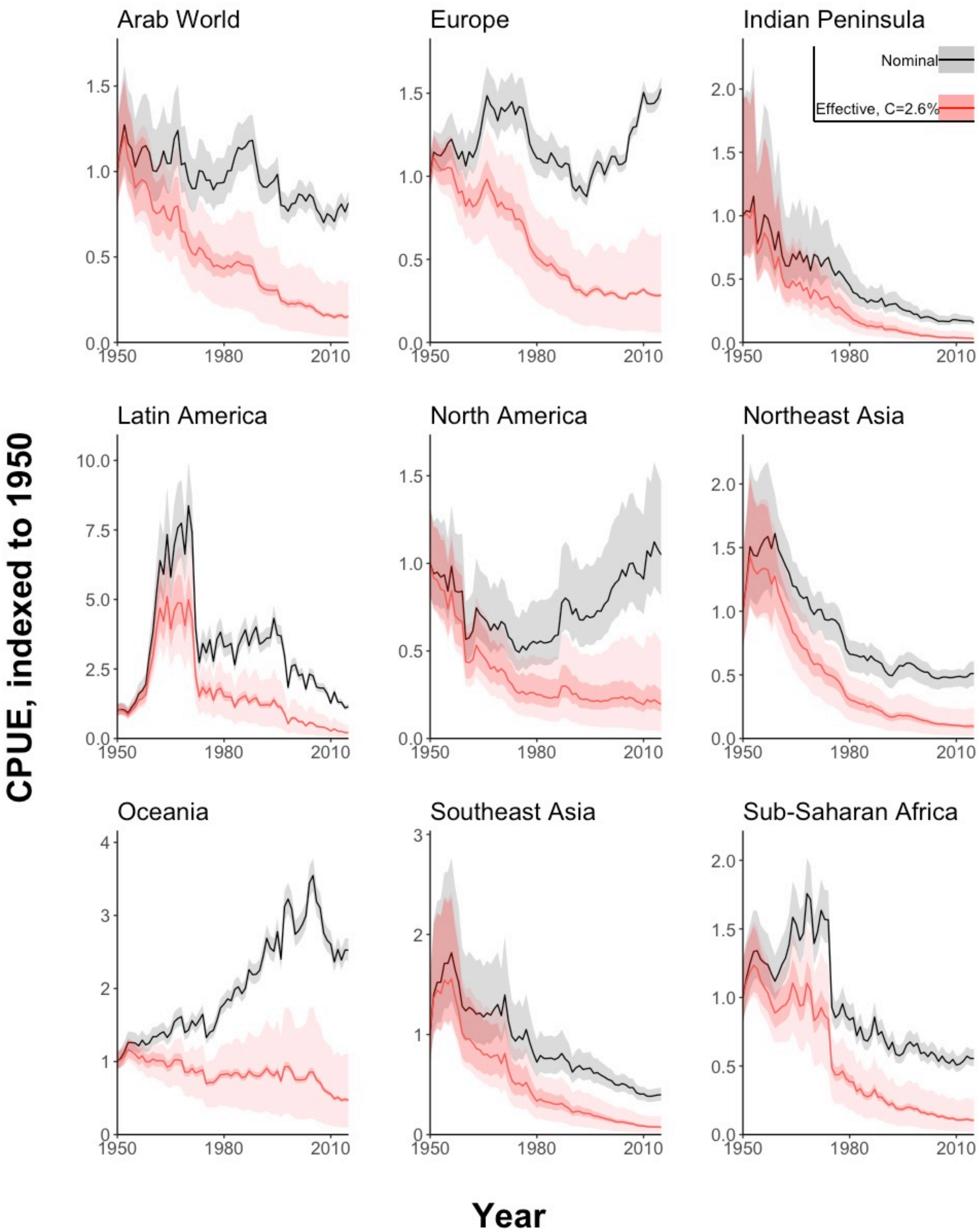

Figure 4.9. Catch per unit of effort, nominal (black) and effective (red) for various regions of the world, including the unpowered fleet, indexed to 1950. Grey and dark pink shaded areas correspond to a one standard deviation error (68 % confidence interval) based on the uncertainty of the engine power alone, light pink shaded area corresponds to a one standard deviation error based on the uncertainty of the engine power and technological creep combined. The effect of the inclusion of the unpowered fleet, comparing with Figure 4.8, is minimal and almost exclusively one of error margins.

4.2.6.4) Catch and catch per unit of effort (CPUE).

The independently developed catch database (Watson et al., 2004; Watson & Tidd, 2018) was used as source of both reported and unreported (illegal, unreported and unregulated, IUU) catches, both artisanal and industrial, for each country and year. Discards were excluded from the analysis, and as such what we call 'catch' in fact referred to 'landings', although we preferred to use the first terminology for clarity.

The catch per country and power class was estimated to be a prorate of the total engine power of said power class to the total engine power of the sector (powered-artisanal or industrial). Both nominal and effective effort were used to calculate and compare the CPUE, here simply defined as

$$CPUE_{year,P_{class}} = \frac{Catch_{year,P_{class}}}{Effort_{year,P_{class}}} \quad (8)$$

All CPUE was indexed to 1950 to aid interpretation. Maps of the indexed nominal (Fig. 4.10) and effective (Fig. 4.11) CPUE for various year showed the variation since 1950. The relatively high indexed CPUE of Finland can be linked to the lack of information about its unmotorized fleet in 1950. Namibia did not have a sufficient non-subsistence catch in 1950 to allow for comparison. The obsolescence of the Russian fishing fleet and the decrease in catch post-dissolution of the USSR accounts for a higher CPUE in 2015. The data was further aggregated by region and sector (artisanal and industrial) and plotted as time series (Fig. 4.12). The relatively low indexed CPUE for the Indian Peninsula's industrial fleet is the consequence of a handful of industrial vessels in 1950, harvesting a comparatively large catch per vessel.

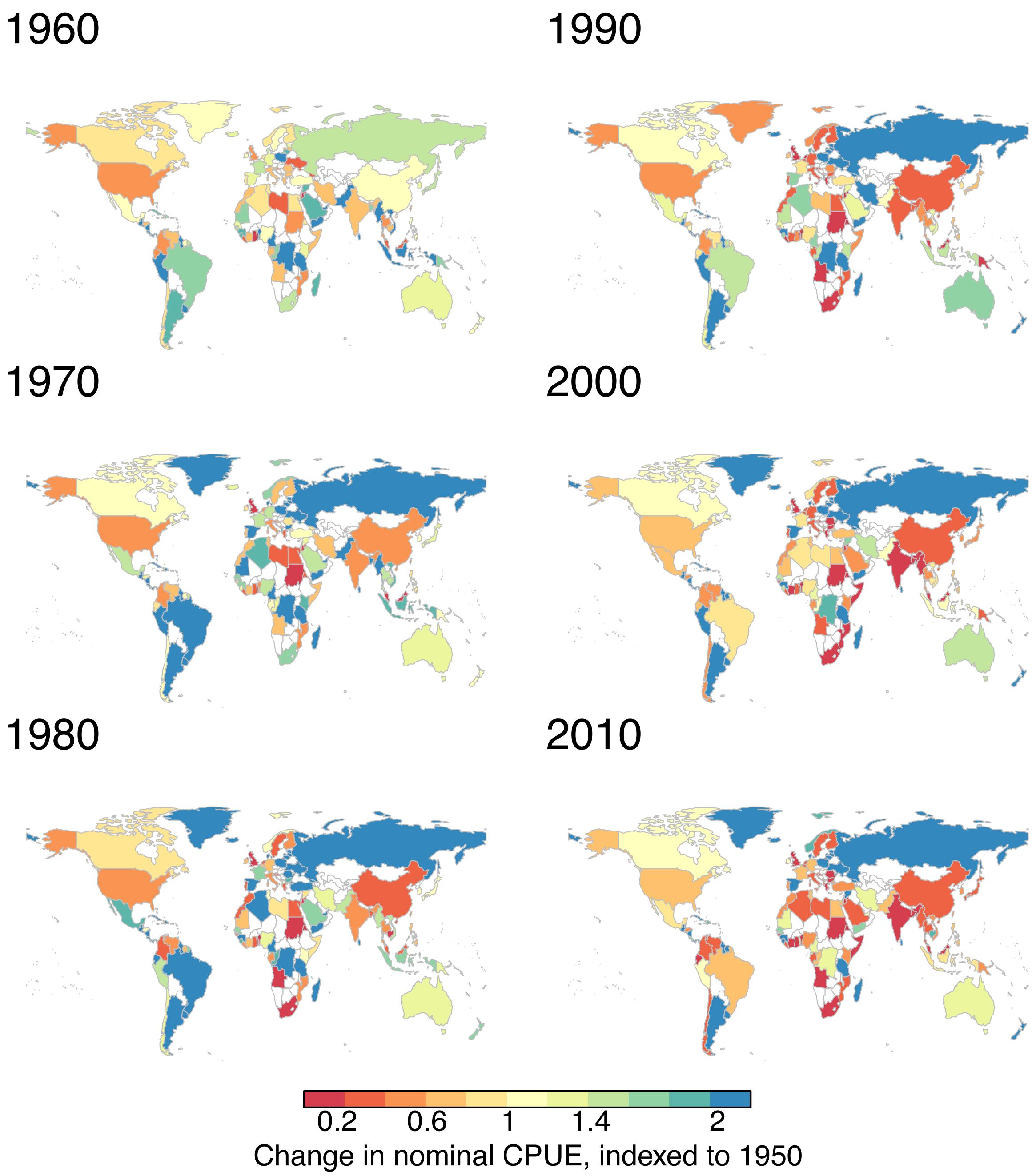

Figure 4.10. Snapshots of the relative change in nominal catch per unit of effort (CPUE), indexed to 1950, from 1960 to 2010.

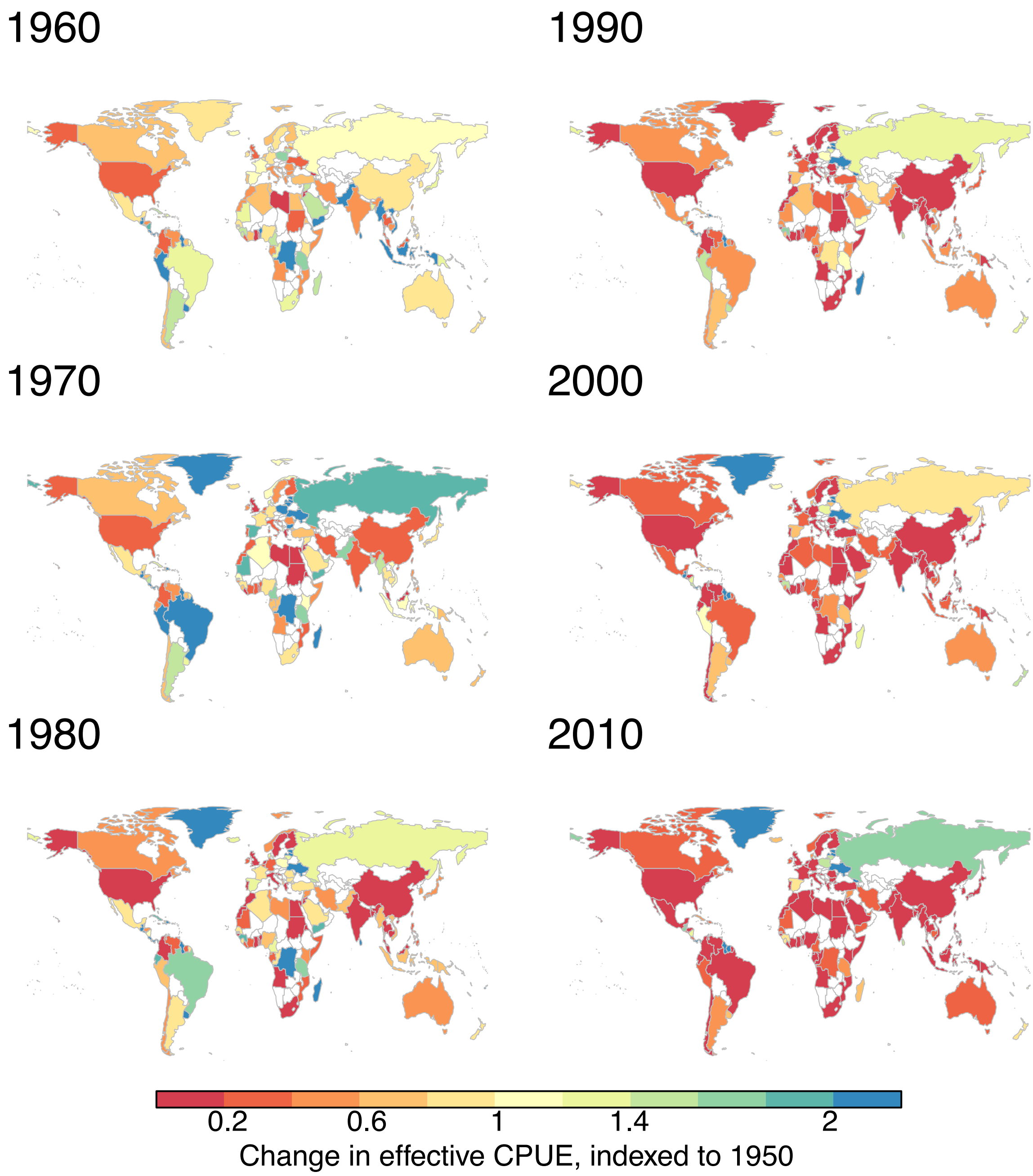

Figure 4.11. Snapshots of the relative change in effective catch per unit of effort (CPUE), indexed to 1950, from 1960 to 2010. The technological creep was chosen as 2.6% per annum.

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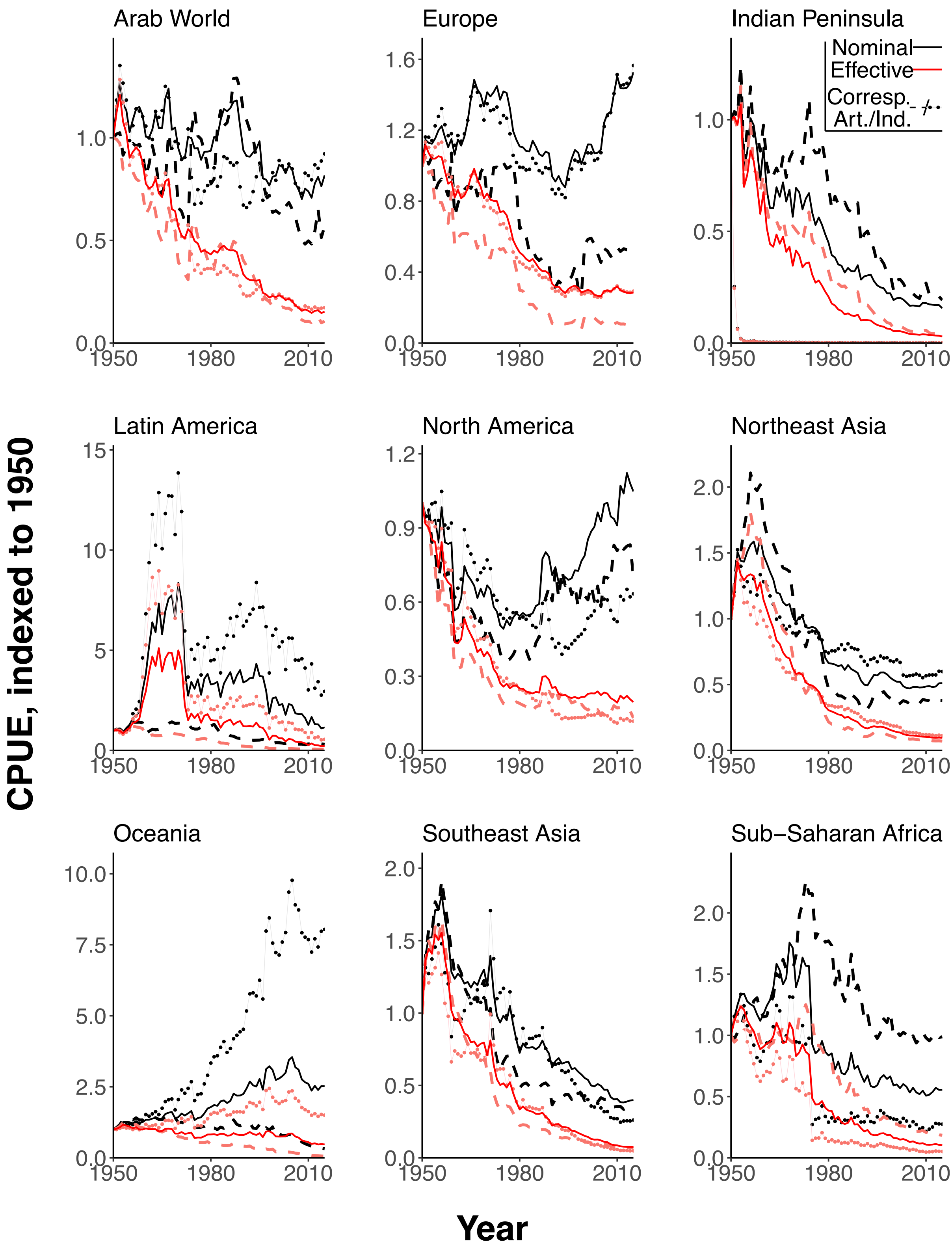


1657 **Figure 4.12. Yearly change in nominal (black) and effective (red) catch per unit of effort (CPUE) by region and sector, 1950-**
1658 **2015, indexed to 1950. The effective CPUE assumes a 2.6% increase in technological creep per annum. Dashed lines**
1659 **represent the artisanal fishing sector (including powered and unpowered), dotted lines the industrial sector, and solid the**
1660 **total CPUE for the region regardless of sector or fleet segment.**

1661

4.2.7) Comparison with stock assessment data.

Stock biomass and spawning biomass data were extracted from the RAM Legacy Stock Assessment Database (www.ramlegacy.org). For each region (corresponding to the CPUE regions as shown in Fig. 4.8 and 4.9), the total biomass for each year was compared (indexed) to the corresponding biomass in 1950. Transboundary stocks (e.g. tuna) were allocated to all regions with access to the waters (e.g. North Atlantic stocks were assumed to 'belong' to North America, Central America, Europe and the Maghreb).

To maintain comparability and avoid variability of results, only time series assessing a minimum of 5 different stocks per region and year, corresponding to 50% or more of the total stocked assessed, were kept. As such, Northeast Asia did not present sufficient data to be included in the analysis, as data was dominated by Japan and did not span the 65 years of our study.
Availability of data was again biased towards the developed world, as, with the exception of stocks specific to Chile and Argentina, the only sources of biomass assessment for developing economies are transboundary stocks.

4.3) Results.

4.3.1) The size and power of the global fishing fleet.

The number of vessels in the global marine fishing fleet doubled from 1.7 in 1950 to 3.7 million in 2015 (Fig. 4.13a). This increase is heterogeneous across the globe, with a drastic increase in the size of the fishing fleet of Asia (defined hereafter as the countries in East Asia and the Indian Peninsula and excluding the Middle East, which were grouped instead with the Maghreb under 'Arab World'), only slightly compensated by a fleet reduction in developed countries, such as observed in North America and Western Europe in the 1990s.

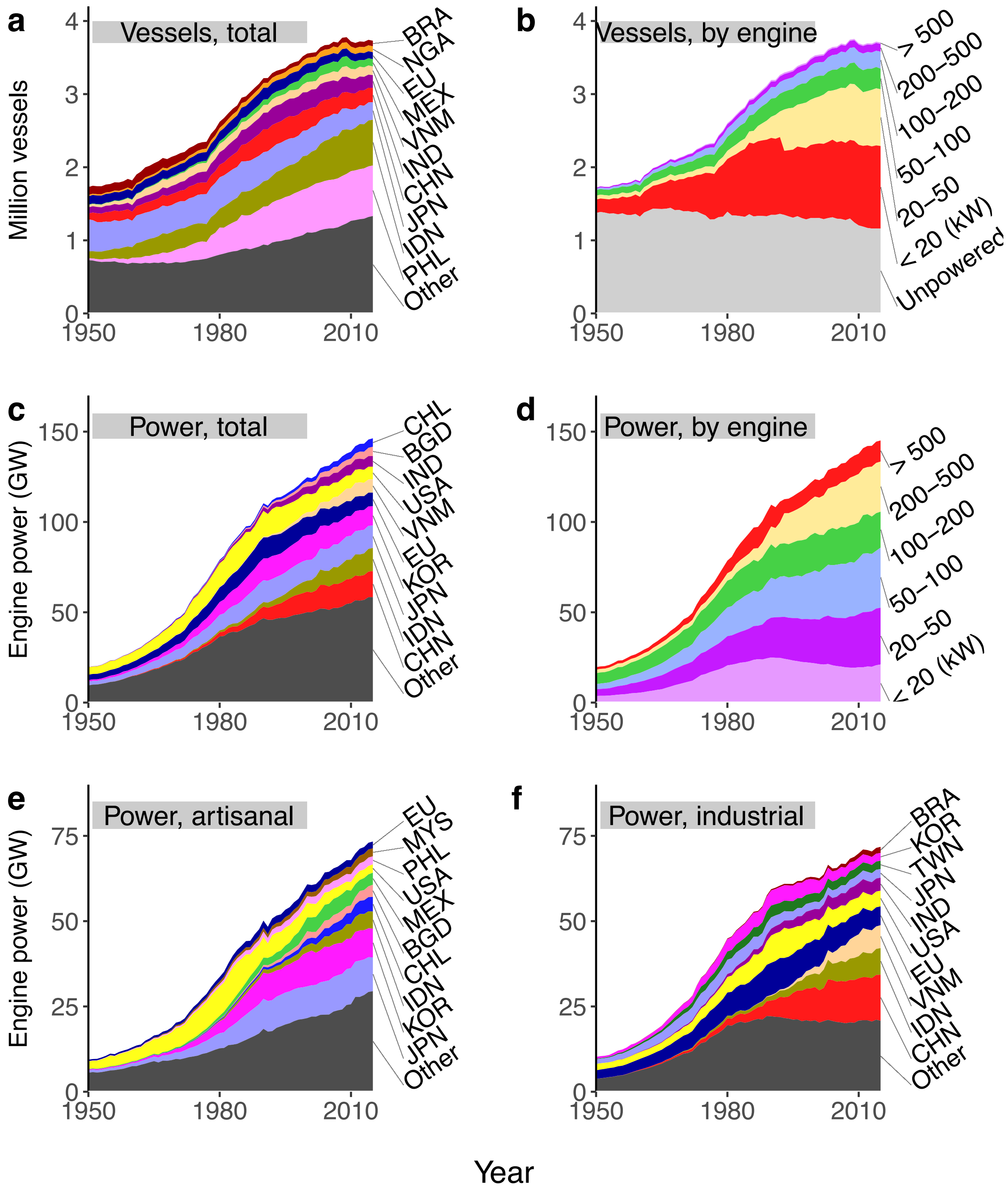


Figure 4.13. Number of vessels in the global fishing fleet by country (a) and power class (b), total engine power of the global fishing fleet by country (c), power class (d), powered-artisanal (e) and industrial (f) sectors 1950-2015. Country labels (except for the European Union, EU) are expressed in ISO 3166-1 standards.

Table 4.2. Number of marine fishing vessels and associated motor power by regions, by fishing sector, at various years.

	Number of vessels (1000)									Motor power (GW)					
	Unpowered			Powered, artisanal			Powered, industrial			Artisanal			Industrial		
	1950	1980	2015	1950	1980	2015	1950	1980	2015	1950	1980	2015	1950	1980	2015
Magreb and Middle East	50	70	65	5	28	134	1	5	11	0.2	1	5.6	0.2	1.1	3
Sub Saharan Africa	68	113	266	2	32	97	1	2	4	0.2	0.9	3.1	0.2	0.9	1.8
Europe*	187	34	8	53	96	80	19	40	30	1.6	3.6	3.5	4.3	16.8	9.5
Oceania**	65	28	39	6	15	45	1	3	4	0.3	0.8	1.7	0.8	1.7	2.4
North America	46	6	1	76	126	41	12	21	19	5.2	11.8	4.4	2	5.2	5
Central America***	45	58	80	7	33	130	1	6	5	0.4	1.8	6.5	0.4	2.2	2.4
South America	123	97	54	7	26	166	0.2	3	8	0.3	1.3	9.7	0.1	1.2	3.4
Indian Peninsula****	108	185	87	6	17	156	0	14	73	0.1	0.5	7.2	0	1.1	5.6
South East Asia	230	596	536	17	231	877	0.7	15	171	0.2	3.3	11.9	0.2	2.7	18.5
North East Asia*****	450	199	23	113	441	387	20	57	115	1	8.6	19.8	2.1	12.2	20.7
World	1371	1385	1161	293	1045	2113	56	167	440	9.4	33.7	73.4	10.2	44.9	72.5

* Incl. Russia. ** Australia, New Zealand and Pacific Islands Nations. *** Incl. Mexico and Caribbean. **** India, Pakistan, Sri Lanka, Maldives and Bangladesh. *****China, Japan, Taiwan, Korea

The magnitude of changes across the three sectors differs substantially. While the unpowered-artisanal fleet declined by 0.2 million between 1950 and 2015, the motorized fleet, both powered-artisanal and industrial, increased more than 6-times over the same period (Table 4.2), accompanied by an increase of the mean engine power (Fig. 4.14d-f). In 2012, we estimate that the global number of marine fishing vessels was 3.7 million, of which 68% were motorized (Fig. 4.14a-c). Our estimates agree with FAO estimates of 3.2 million and 70% respectively (FAO, 2014b). Parenthetically, while the 2018 SOFIA report (FAO, 2018) estimates 4.6million vessels globally in 2016, this includes inland fishing fleet, excluded from our analysis. A simple proportionality rule with regard to the last disaggregated data indicates that, based on FAO data, the number of marine vessels decreased to 3.1 million in 2016, compared with our estimates which increased to 3.7million in 2015. Similar differences are observed in the unmotorized marine fleet in 2015/16, estimated from SOFIA 2018 to be under 1million, compared with our estimate of 1.2million. Our estimates of the total engine power, however, is only half of that given by previous global studies (Fig. 4.15).

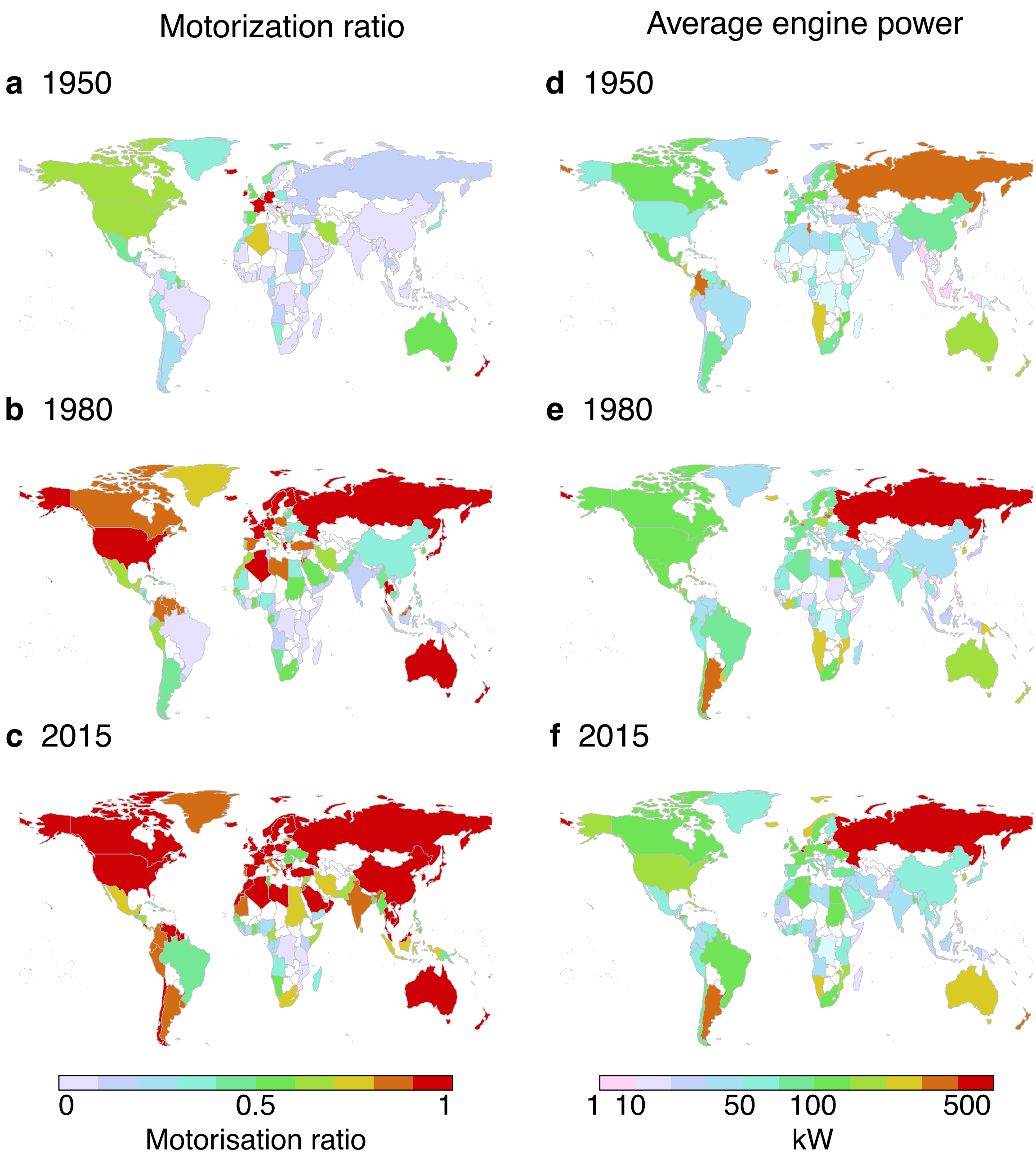


Figure 4.14. Snapshots of the ratio of motorization (a,b,c) and average engine power in kW (d,e,f) of the national motorized fishing fleet in 1950, 1980 and 2015, respectively. Motorization levels in European Countries in 1950 might be overestimated, due to the lack of data post World War II. No data for the unmotorized fleet of Finland was found, but it was assumed that the motorization level was close to 100% since the 70s, similar to other Scandinavian countries.

The motor power of the entire global fishing fleet increased quasi-exponentially from 1950-1990s followed by a period of slower growth up to 2015 (Fig. 4.13c). Until the 1980s, the growth of both industrial and powered-artisanal engine power followed similar trends (Fig. 4.13e and 4.13f). In the last three decades, however, the growth of industrial fleets has slowed considerably, and now the total engine power of the powered-artisanal sector is equal to that of the industrial. It is important to note, however, that the vastly varying definitions of artisanal fishing globally imply a certain level of uncertainty and overlap.

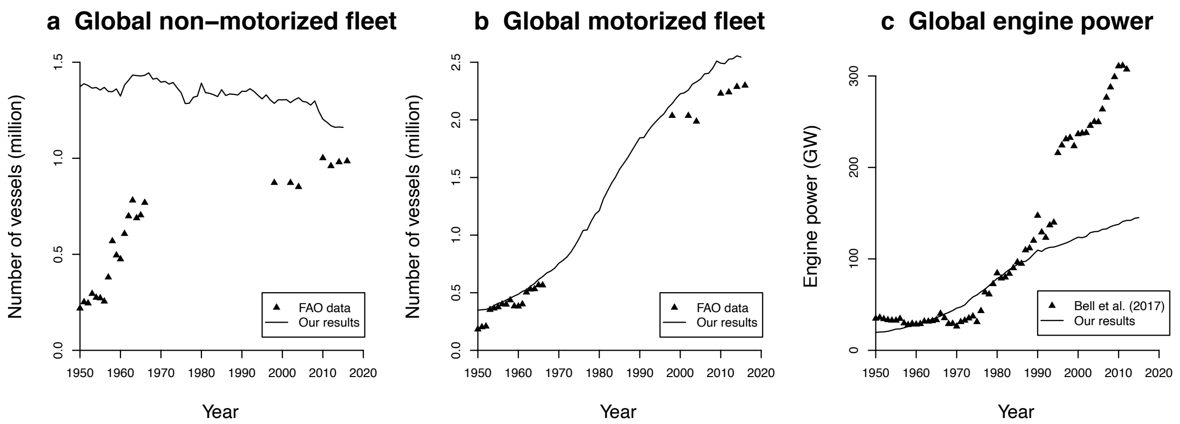


Figure 4.15. Comparison of the results of this study with data from previous study. The comparison includes estimates from the FAO (FAO, n.d.-d, 2011b, 2015c) and Bell et al. (Bell et al., 2017) for the number of vessels in the global unpowered (a) and motorized (b) marine fleets, and the global engine power of the marine fleet (c).

Regionally, the power of European, North American and Australian fleets more than doubled from the 50s to the 80s, followed by drastic reduction in the 2010s (Table 4.2). Their share of the global fleet, however, dropped drastically, especially its unpowered-artisanal component. By contrast, the Asian share of the global fleet and their total engine power have increased 4 times since 1950. This increase is particularly striking in Southeast Asian countries, where their relative share of the power increased over 10 times in the period.

Powered-artisanal and industrial sectors aside, a strong heterogeneity in the different power classes was evident. Small powered vessels now make up a vast portion of the global motorized fleet in numbers but do not represent a large portion of the engine power (Fig.4.13b & d). In contrast, the large powered vessels represent less than 5% of the fleet but account for a third of the total engine power. The regional and temporal differences are equally striking, with the developed world fleet drastically reducing their capacity of both smaller and larger vessels while the same components of the Asian fleet vastly expanded.

4.3.2) Effort and catch per unit of effort (CPUE).

The global nominal and effective effort increased steadily from 1950 to 1980 across all regions and sectors (Fig. 4.16). Since the 1980s, however, some variability has been observed. While the nominal effort of both the European industrial sector and the North American (USA and Canada) fleet (both sectors) decreased, the effective effort stabilized in recent years due to the increase in technological efficiency. Though European and Northeast Asian (China, Taiwan, Japan, Korea) nominal artisanal effort stabilized, the corresponding effective effort continued to increase.

The European and Oceanian industrial fishing effort was consistently greater than the artisanal effort throughout the time range studied, while North American and Southeast Asian industrial effort overtook their artisanal counterparts in the 1980s and 2000s, respectively. The artisanal and industrial effort of the Indian Peninsula and Northeast Asia have been closely matched, while the artisanal effort of Africa, the Arab World and Latin America was consistently greater than their industrial counterparts.

Sectorial and regional variability was greater in the CPUE (Fig. 4.17). While the nominal CPUE of Asian fleets consistently decreased relative to 1950, and Oceania's increased throughout the same period, other regions showed some variability. Latin America had a steep increase in the 60s, followed by an equally fast decline in the early 70s, while the fall in the European nominal CPUE occurred throughout the 80s. The relatively low indexed CPUE for the Indian Peninsula's industrial fleet is the consequence of a handful of industrial vessels in 1950, harvesting a comparatively large catch per

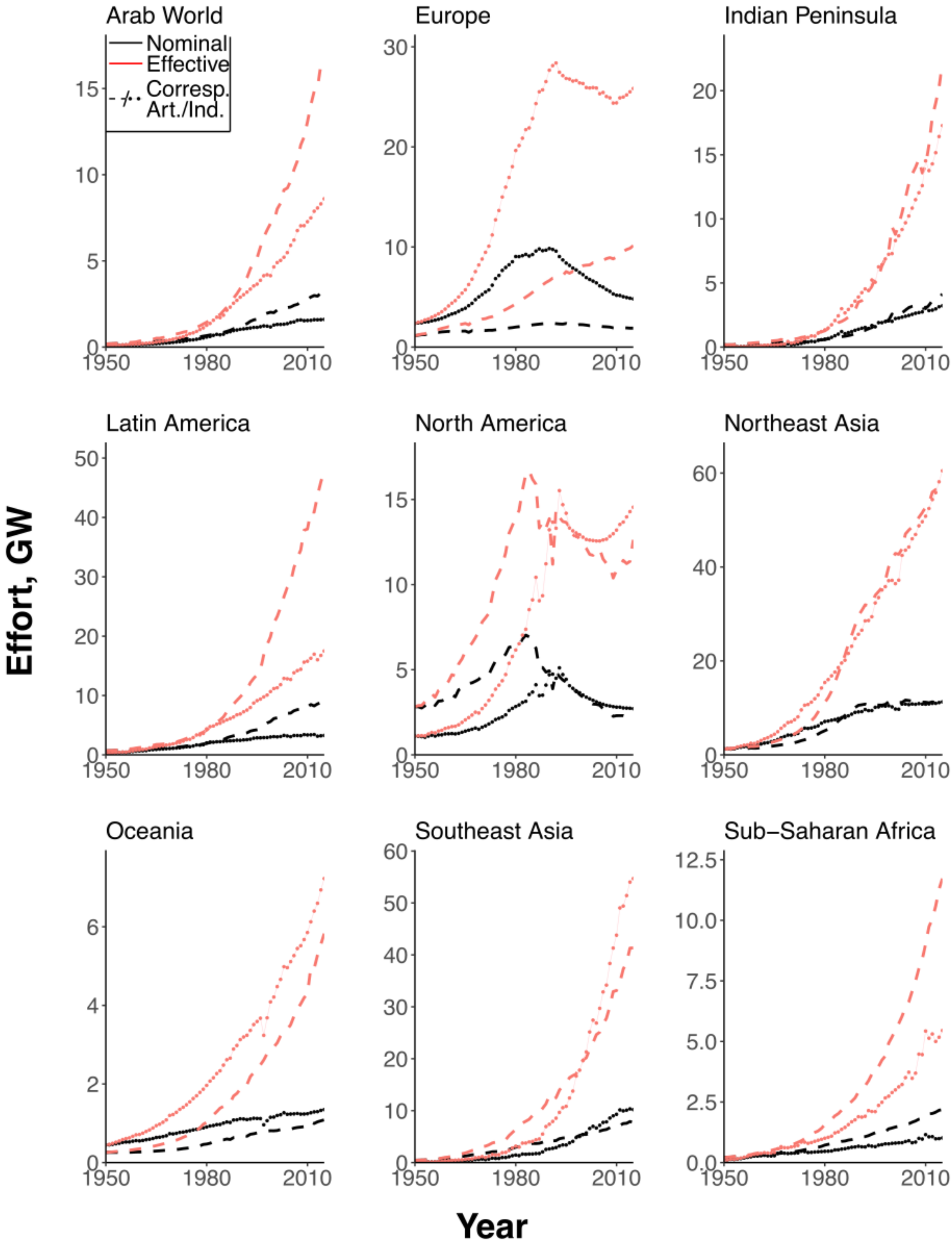


Figure 4.16. Yearly nominal (black) and effective (red) fishing effort by region and sector, 1950-2015, averaged per day. The effective effort assumes a 2.6% increase in technological creep per annum. Dashed lines represent the artisanal fishing sector (including powered and unpowered), and dotted lines the industrial sector.

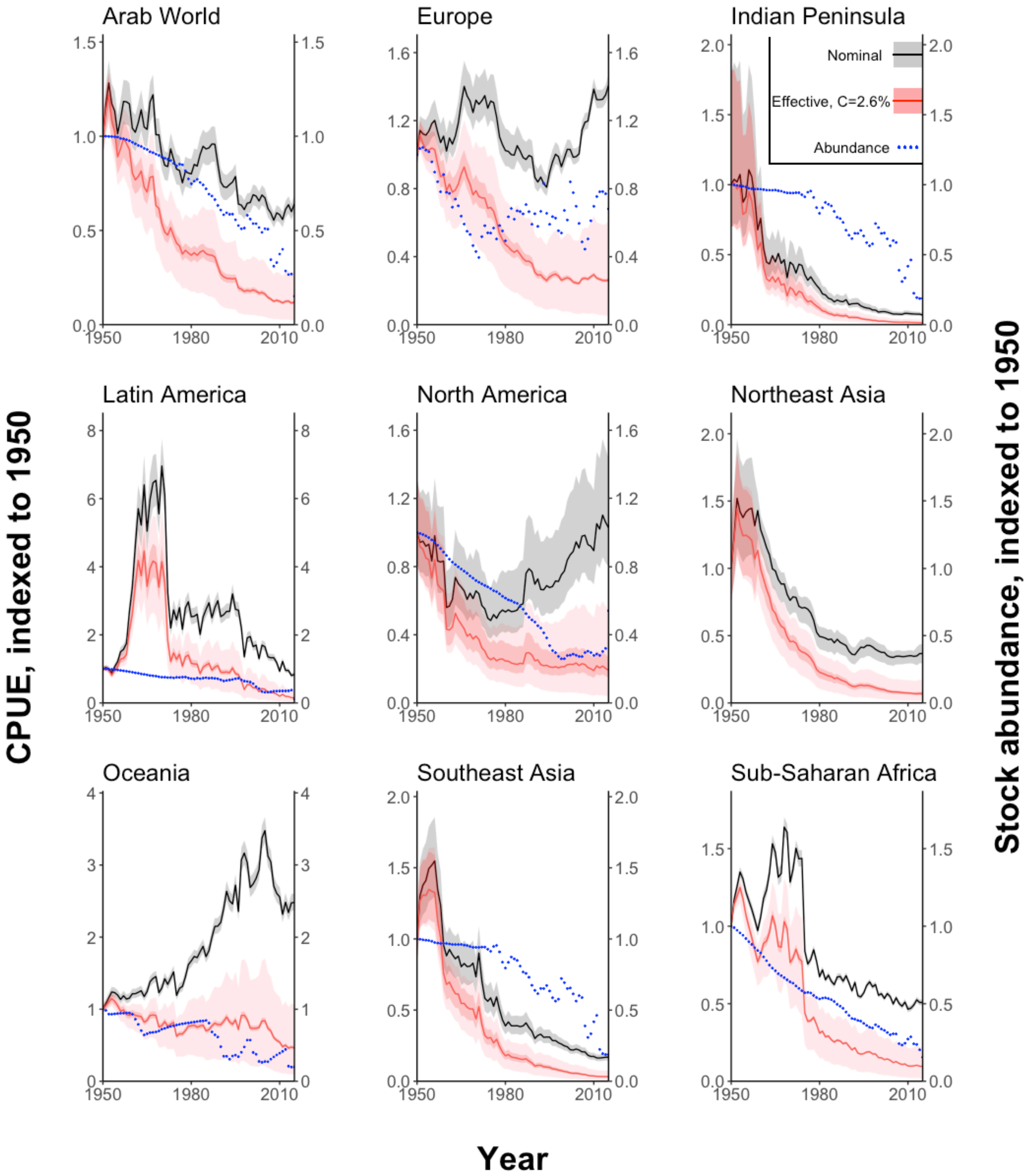


Figure 4.17. Yearly change in nominal (black) and effective (red) CPUE and stock abundance (dotted blue) by region, 1950–2015, indexed to 1950. The effective CPUE assumes a 2.6% increase in technological creep per annum. The grey and dark pink shaded areas correspond to one SD error (68% confidence interval) based on the uncertainty of the engine power alone, the light pink shaded area corresponds to one SD error based on the uncertainty of the engine power and technological creep combined. Abundance was expressed in terms of the total assessed biomass or spawning biomass. The y axes were aligned to facilitate comparison.

vessel. Of all regions, only Europe and the Indian Peninsula showed a trend in the total indexed nominal CPUE that closely followed that of the industrial sector in both amplitude and variability. The relative effective effort followed a general downward trend, due to the added effect of the yearly technological efficiency creep. Over the period 2000-2015, the nominal CPUE of Europe and North America increased on average by 2.5% and 2.1% per year respectively, while that of the Indian Peninsula, Southeast Asia and Latin America dropped by 1.3%, 2.1% and 4.1% respectively (Fig. 4.18a). The rate of change in nominal CPUE in the rest of the world was stable over the same period, with less than 0.3% a year (increase or decrease).

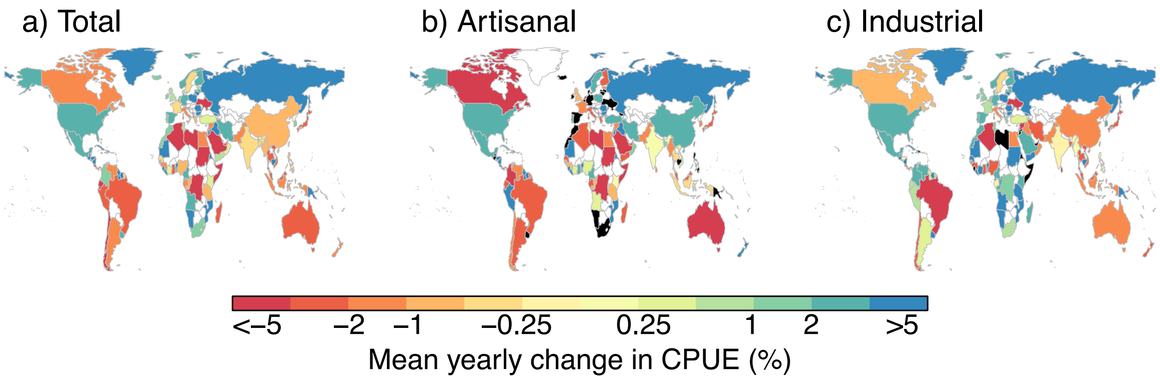


Figure 4.18. Mean yearly change in nominal CPUE per country between 2000 and 2015. Countries in black do not have enough information to meaningfully calculate the rate of change according to sectors.

4.4) Discussion.

4.4.1) Data availability and credibility.

Reconstructing the number of vessels in the world's fishing fleet presents multiple challenges. Data is often biased towards industrial vessels and underestimates the numbers of artisanal vessels. It is not uncommon for national fishery departments to report only their industrial fleets (e.g. Albania) or even a portion of it (e.g. Pacific Islands Nations reported only tuna vessels while Peru reported only fleets targeting their anchoveta stock)[10], despite the prevalence of smaller, powered-artisanal vessels (FAO, 2018). Studies and country reports sometimes focus exclusively on either registered, licensed or officially active vessels, each a subset of the total fishing fleet. This in turn can lead to strong underestimates of the national fishing fleet and its effort (Anticamara et al., 2011; Bell et al., 2017), which, if not taken into account by policies and effective management, can in turn lead to economic losses, increase in levels of IUU fishing or discrepancies in stock assessments. A further implied consequence of misreporting fleets is that, if and when catches or fish stocks collapse, it appears to an external observer as if the fishing fleet has simply collapsed with it. Though it is undeniable that the disappearance of a target stock will heavily impact the number of fishing vessels over the years (as seen for instance after the collapse of the Peruvian anchoveta in the 70s), vessels do not disappear without trace from one year to another. In the years it takes for management to deal with a surplus of unused vessels, the fleet will typically move on to other stocks and locations (Belhabib et al., 2015). The misinterpretation that the active fleet is actually the total number of fishing vessels in a country is, in turn, cited in further studies, and the distorted unreported statistics are further perpetuated.

Lack of governmental transparency presents further obstacles to the availability of trustworthy data. Data were limited or falsified during the Soviet era, the dictatorship in Chile under Pinochet and for a handful of African nations. Some countries have been known to adjust their marine catch statistics (Watson & Pauly, 2001), and it is expected that such artefacts also exist in their reports of fishing capacity. While the FAO has taken steps in recent years to reduce the propagation of misreporting, historical databases can still present easily perpetuated biases.

[10] For literature and data source on specific countries hereafter, please refer to the Tables and explanatory documentation in Appendixes 3 and 4.

4.4.2) Quantifying fishing sectors.

Lack of historical data and the use of GDP as a proxy for motorization leads to uncertainty in both the size of the historical unmotorized fleet and the rate at which motors have replaced oars and sails, particularly in the richest countries. The latest SOFIA report (FAO, 2018) states that the number of non-motorized vessels has increased in recent years due to improved reporting but, as it does not disaggregate inland and marine fisheries, it is unclear whether their observation supports our results. The size of the unpowered-artisanal fleet could be higher and the global motorization levels lower than we estimated here. Indeed, this is suggested by the lack of information found for the unpowered-artisanal fleet of the Arabic peninsula, and the contradictions in the fleet reported by Small Island Nations. We argue, however, that the effect of the unmotorized fleet on fishing grounds, while potentially high locally and on specific species targeted for subsistence, is often minimal compared to the motorized segments, as shown by our CPUE calculations (Fig. 4.8 and 4.9).

Although the industrial fishing fleet is often better reported, some of these concerns also apply to the powered-artisanal sector. The number of boats retrofitted with an engine is difficult to assess, although censuses are more abundant for this sector than the unmotorized one and allow for cross-validation and sharper estimates. Their impact on fishing grounds, however, is far from negligible, as can be seen for instance in the Philippines municipal fisheries. It is important to note that no distinction was made between artisanal, small scale, subsistence and traditional sectors in this study. Any vessel which fell under country-specific definitions was considered ‘artisanal’ (further detail in Appendixes 3 and 4).

Our study shows that artisanal fleets already have total power levels comparable with industrial fleets and, while the sector is receiving less fuel and capacity subsidies (Sumaila et al., 2013), it is also less restricted and monitored. The fishing effort of the artisanal fleet is in all regions but Europe and Oceania equal or larger than the industrial effort, suggesting that the artisanal sector could play an important role in global overfishing. Scarcity of data and lack of a unified definition of what is 'artisanal', however, suggest caution when comparing data across regions. In particular, the measure of the CPUE is difficult to separate by sector. While the industrial catch is often clearly reported, not only is the artisanal under-documented, but studies and countries use their own definitions of what artisanal catch is, which might not be directly compatible with either legal definitions or definitions used in other studies. For instance, while one might separate the artisanal catch from the industrial with depth and distance to shore (Watson & Tidd, 2018), a large portion of the 'legally' industrial fleet of the EU (i.e. the vessels over 12m in length) are known to fish in coastal waters (Guyader et al., 2013), effectively leading to overlaps between sectorial CPUE.

This use of country-specific definitions for the artisanal/industrial sectors rather than a blanket one, however, hinders the meaning of a direct comparison of the sectors of countries with different definitions. The FAO (FAO, 2018) circumvents this issue by using vessel length classes (under 12m and over 24m), while we preferred to compare engine power, which is more meaningful for future examination of the energy intensity of fleets and associated fuel use and greenhouse gas production, and allows for the separation of the artisanal sector into unpowered and powered. While this approach is extendable to the fishing effort, catch data is not yet disaggregated to allow for a comparison of the CPUE between classes of engine power. Recreational Fisheries are absent from our study but are by no means unimportant. Over half a million recreational vessels are present in Australia alone (Commonwealth of Australia, 2003), over 50 times that of artisanal and industrial fishing vessels combined, with catch of comparable levels or sometimes exceeding the commercial sector (McPhee, Leadbitter, & Skilleter, 2002). This is common in developed countries (Cooke & Cowx, 2004).

Although our estimates of the number of vessels agrees with other studies (FAO, 2018), our estimates of the engine power and thus the effort starkly contrast with previous ones (Bell et al., 2017) (Fig. 4.15). The separation of the fleet by sector is a fundamental difference in our methodology and explains a vast portion of the difference. Further, the use of 'similar countries' to estimate the average engine power of data-poor countries, while limited in its depth, is an improvement over using data from developed, technologically advanced countries' (e.g. EU fleet register) and extrapolating this to the quite dissimilar fleets of developing countries.

4.4.3) Modernization of fleets and management.

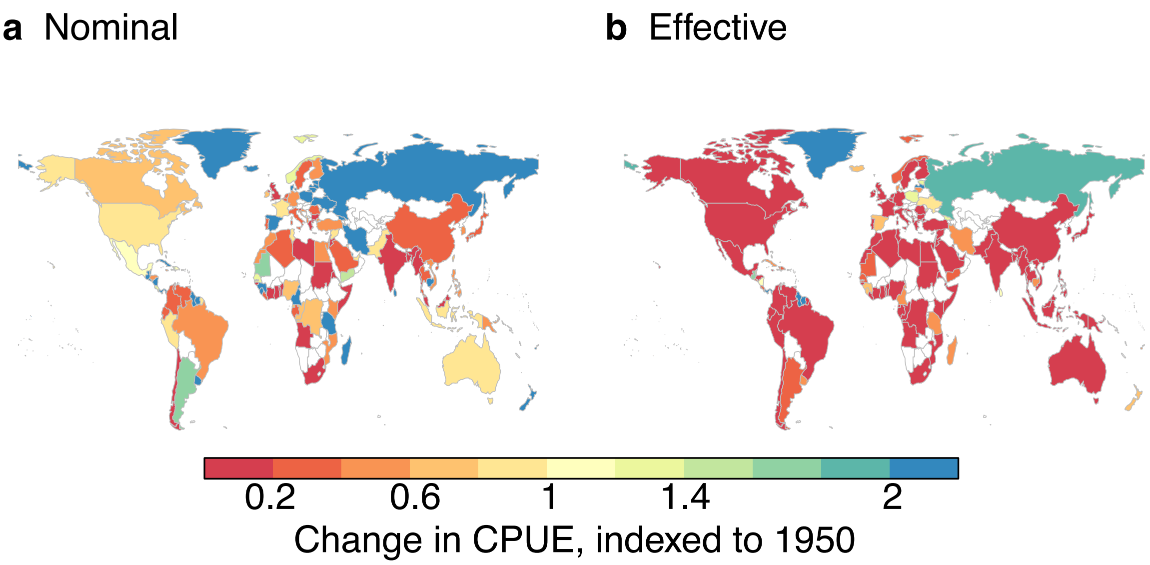


Figure 4.19. Snapshots of the 2015 relative change in nominal (a) and effective (b) catch per unit of effort (CPUE), indexed to 1950. The technological creep estimated at 2.6% per annum.

Technology transfer and improvement in engine design have vastly impacted the motorization of the global fleet. The developed countries' fleet started their motorization in the first part of the 20th century, by developing coal-powered vessels. This technology has been rendered mostly obsolete with massive improvement in the cost-efficiency of petroleum-based motors. In particular, the development of portable motors was a game-changer in fisheries. In the developing world, outboard motors have become more and more prominent, and allowed for more flexibility in the development of the fleet. Most of the vessels equipped with an outboard motor remain artisanal, but it not uncommon to see boats retrofitted with motors of over 50kW. This is particularly true in Southeast

Asia, where hundreds of thousands of vessels equipped with outboard motors are present. Retrofitting likely has a considerable effect on the sustainability of (powered) artisanal fisheries, with increased pressure on stocks and a rise in greenhouse gas emissions from fuels. The increased pressure that this motorization has had on fishing stocks is particularly felt in Africa and Southeast Asia, reflected in the drop in CPUE since 1950, both nominal and effective (Fig. 4.19). This pattern mirrors what has been seen elsewhere, such in North America where the rapid motorization of the fishing fleets in the 1950s was likewise accompanied by a decrease of the relative nominal CPUE in both regions.

Our analysis shows that the effective effort increased at a much faster rate throughout the world than the corresponding catch, although signs of a stabilization appear for Europe and North America since the 1990s. Although the effective CPUE of Oceania decreased, the observed rate is comparatively lower than the rest of the world. This indicates that, while a general reduction in abundance is observed throughout the world, the observed stabilization in North America and Europe and slower rate of decline in Oceania are consistent with the impact of fisheries management in these regions (Mora et al., 2009). In contrast, using the effective CPUE as a simple direct measure of stock abundance, paints a dark picture of the oceans' resources. The rapid decrease in the relative effective CPUE, however, is fundamentally linked to estimates of the technological creep. A creep of 2.6% per year corresponds to a 5-fold increase in fishing efficiency over a 65 years period. As a measure of the increased efficiency of fishing techniques, the uncertainty on this parameter is consequential and translates to vastly incremental uncertainties on CPUE. Although no distinction is found between the creep of artisanal and industrial fleet (Pauly & Deng Palomares, 2010), available data for its calculation is almost exclusively sourced from developed countries, making calculated trends elsewhere less reliable. Our findings that Europe and North America had a rate of change in nominal CPUE over the last 15 years over 2% per year indicates that only these regions are adapting their fisheries management strategies to a sufficient extent to account for increase in technological efficiency. In Southeast Asia, Latin America and the Southern Mediterranean, the drop in nominal CPUE over the same period indicates that the expansion of the fisheries occurred at a much faster rate than fish stocks could support. Combined with the high uncertainty on the increase in technological efficiency, particularly its temporal and regional variations, additional management measures seem urgently warranted. This decline is of particular importance in regions where the artisanal fleet sustains a considerable portion of the population, such as Southeast Asia. As agricultural systems connect on both land and seas (Cottrell et al., 2018), overfishing and an imminent decline, marked by uncertainties on the sectorial CPUE and potentially underestimated landings, could ripple throughout the economy and impact future food security.

The highly variable geopolitical map and its impact on fishing fleets further complicates our understanding of the evolution of fleets and their management. European colonial empires explain the high mean power in Africa in the 1950s and 1960s, and the reduction in subsequent decades, even while the mean generally increased elsewhere. It is uncertain, however, how much of this effect lingered, as old segments of their fleet might have been ‘left behind’. By contrast, the independence of Timor-Leste from Portugal and then Indonesia led to the quasi total destruction of their fleet. The instability and economic disparity in the Middle East can be seen through various levels of motorization, with strict policies and management explaining the levelling of the Emirates fleet, while conflicts in other countries have greatly reduced the capacity (PERSGA, 2002). Although EU countries are at different economic levels, there is a common push from the Union to reduce the fishing fleet (Engelhard, Lynam, García-Carreras, Dolder, & Mackinson, 2015), effectively prompting the reduction of the fleet even in the poorest countries of the block. The bottom line is that, while countries will reach a peak fishing fleet, the drivers for this are a composite of local biology, climate, management, economics and politics (Barange et al., 2011), and remains both complex and incompletely explained.

Some variation of the CPUE can be similarly directly linked to specific occurrences in fishing history. Our data clearly shows the rise and fall of the Peruvian anchoveta fleet in the 1960s (Fig. 4.17), while the dent in relative nominal CPUE in Europe around 1990 can be linked to the dissolution of the

USSR and the resulting drop in catch. While indexed CPUE is often used as a proxy of the relative well-being of stocks, we suggest caution when comparing it to 1950, as the accuracy and completeness of fleet data of the period is questionable. Conversely, one can think of 1950 as a semi-pristine state of the world's fisheries, and the drop in CPUE in the following decades was a consequence of unchecked modernization and expansion.

4.5) Conclusion.

Despite decreasing global catches (Pauly & Zeller, 2016a) and falling CPUE, we have shown that the global fishing fleet has kept on increasing. If past trends continue, with a 1:1 ratio for the motorization, up to another million powered vessels could appear in the global fishing fleet over the next few decades, with potential for changes in access rights and catch reallocation, increased stress on ocean resources and increased fuel emissions contributing to climate change. Furthermore, the mean engine power of the fishing vessels per country is still increasing.

Recent signs of stabilization in the effective CPUE were observable for most developed countries, although these still represent the minority of locations. This might evolve in the near future, however, as fuel efficiency becomes paramount in discussions on mitigating climate change, and management of the fleet in reaching a sustainable use of the marine resources.

Finally, previous reconstruction methods have attempted to extrapolate global data from a subset of the European fleet, leading to inflated results. We distanced ourselves from this bias in the calculation of the engine power, but further work is required to quantify the impact of socio-cultural factors on the evolution of fishing fleets beyond simple reconstruction. The importance of regionally-varied rates of technological change, if present, could vastly affect the global fishing effort, but the literature remains sparse. A deep understanding of both the size and motorization of artisanal and industrial fishing fleet is needed to estimate global fishing effort and its impact on ecosystems, livelihood and employment. In particular, this study opens up the space to future work on comparing global CPUE assessment to CPUE-independent biomass assessments. Quantifying these is a necessary step toward understanding global fleet dynamics and their integration into more holistic models of global fisheries required to safeguard vital ocean resources.

Chapter 5 - Mapping global fisheries: balancing gaps and overconfidence in data.

5.1) Introduction.

Marine fisheries historically have been a major source for nutrition, employment and livelihood (FAO, 2018), and are likely to remain so in the future. In recent years, there has been a push towards inclusion of fisheries-data in global ecological models in order to address the multiple challenges that the sector faces, such as climate change (Cheung, Jones, et al., 2016), depletion of the oceans (Worm, 2016), and dependence on the productivity of adjacent terrestrial systems (Cottrell et al., 2018). Fisheries yields are ultimately limited by the size of the stocks and interaction with their supporting marine ecosystems, all of which are spatially dependent.

With the widespread nature of fishing and its impact on ecosystems, there is a need for detailed understanding of fishing effort, particularly geographical and historical patterns (Collie et al., 2016; Galbraith et al., 2017). While the integration of fishing effort into ecosystem models is not new, spatially disaggregated effort is a more recent affair (Watson et al., 2004). While such global mapping used to be based on reports of catch and international agreements, recent advances in standardisation of telecommunication systems has provided insights on the precise location of the vessels (Kroodsma et al., 2018). Vessel automatic identification systems (AIS) can indeed be used to infer the location of the fishing effort and AIS has shown itself a promising instrument for tracking the effort of fishing fleets (Kroodsma et al., 2018).

While the wide-spread adoption of AIS might prove extremely useful for fisheries management, there is a need to understand the limitations of the knowledge gained from them, if only to avoid falling into the 'technology effect' fallacy (Clark, Robert, & Hampton, 2016), a tendency to overestimate the success of implementing new technologies. In particular, concerns have been raised over large-scale manipulation of AIS data and its links to corruption (Bondaroff, Van Der Werf, & Reitano, 2015), raising questions on the validity of the former. Furthermore, AIS data is heavily dependent on receiver coverage, leading to a heterogenous accuracy across the globe (Kroodsma et al., 2018). Comparing AIS with catch-based methods for mapping fishing effort (Watson et al., 2004) could be a step towards cross validation and complementation, but has been carried out at global level so far.

While it is undeniable that AIS data gives the highest degree of precision in locating fishing vessels, it is necessary to analyse it in order to find its scope, depth and limitations, and to develop a method that allows comparability. The aims of this chapter are to do spatial and temporal mapping of the updated effort data (Rousseau, Watson, Blanchard & Fulton, 2019b), and to compare with mapped AIS tracking data presented in the Global Fishing Watch database (globalfishingwatch.org), in order to verify the validity, gaps and biases of both method, and direct future research.

5.2) Data and methods.

Several steps were involved in converting existing effort data into metrics that could be compared to the AIS data, as explained in the steps below (Fig. 5.1).

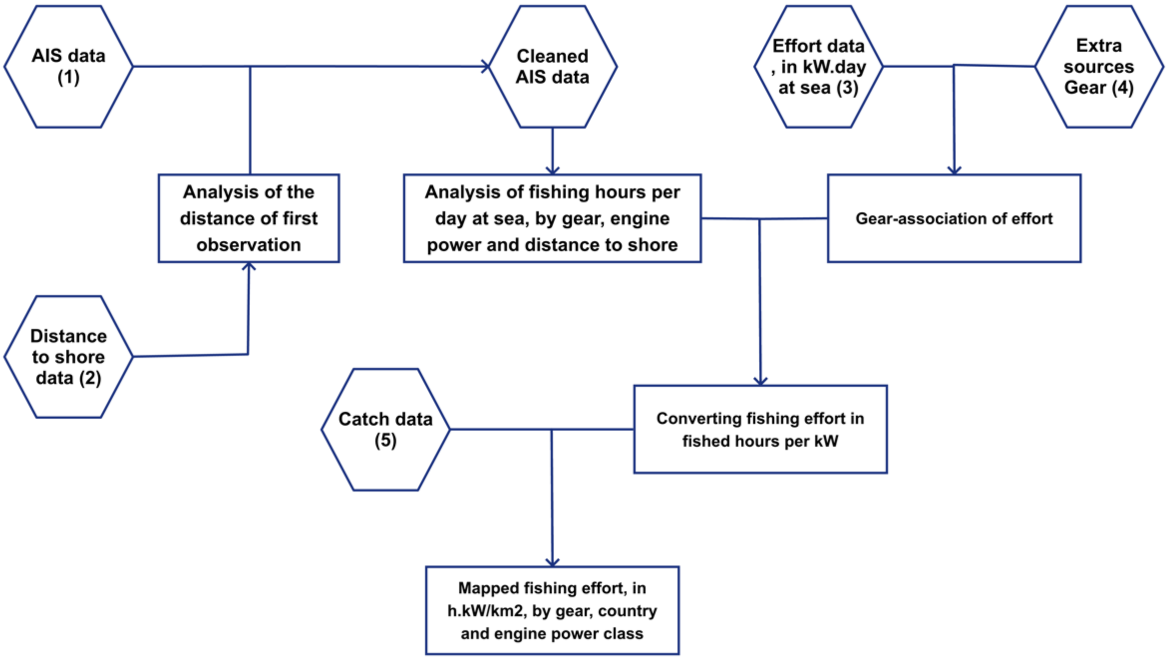


Figure 5.1. Methods and data source used for mapping the fishing effort.

Data sources: (1) globalfishwatch.org
(2) oceancolor.gsfc.nasa.go
(3) (Rousseau, Watson, Blanchard & Fulton, 2019b)
(4) Databases from European Union, Tuna RFMOs, FAO, … See in text and Appendix 3 for details.
(5) (Watson, 2019)

5.2.1) Analysis of AIS Data.

5.2.1.1) Data pre-processing.

Pre-processed (Kroodsma et al., 2018) fishing fleet AIS tracking data for 2016 was downloaded from Global Fishing Watch – globalfishingwatch.org. Two specific datasets were used: 1) the vessel position data by maritime mobile service (MMSI, given in 1/10th of a degree cell) and 2) the fishing hours by country (given in 1/100th degree cell). The vessel data was associated with the MMSI registry (also extracted from globalfishingwatch.org) through country flag, engine power, gross tonnage, and fishing gear. Data from 54,753 fishing vessels (excluding those only involved in support and cargo) could be associated. In total 9 categories of fishing gear (see Appendix 6 for details) were retained for the analysis, and 7 out of the 10 engine power classes previously defined (Rousseau, Watson, Blanchard & Fulton, 2019b).

For each day represented in the combined datasets, a day at sea was given to each individual vessel spending at least 0.1h at sea, a rounding of the 'observed 5 minute interval' used in the Global Fishing Watch methodology, the minimal time under which observation of an AIS signal was considered valid. Each cell of the vessel effort database was converted into a distance to the shore based on NASA's "Distance to the Nearest Coast" data (oceancolor.gsfc.nasa.go).

5.2.1.2) Linking observation rates to corruption.

Each individual vessel of the AIS dataset was associated with the maximum distance to shore at which it was observed during the year (D_{max}, in km). A vessel was considered observed at distance X from the coast (by 1km increment) if an AIS signal emitted by the vessel was received at least once during the year at that distance. The observation rate was defined as the ratio of unique observations to the maximum distance to the shore at which it was observed:

$$Observation\ Rate = \frac{\sum_{X=1}^{D_{max}} Unique\ observation\ at\ distance\ X}{D_{max}} \qquad (5.1)$$

Given that AIS signals are broadcasted every few seconds for moving vessel, an individual vessel **should** have been observed at every kilometre leading to D_{max} at least once (Observation rate of 1). Considering that the maximum resolution of AIS data is of 1/10th degree, corresponding to approximately 11km, in theory every vessel should have been observed at least once within 11km of the coast. Thus, an observation rate of less than 1 for vessels within 11km of the nearest coast would indicate either misreporting or manipulation of the data. While some of these discrepancies could potentially be caused by gaps in the data processing methodology or accidental misreporting, some could be intentional. Assuming that willing misreporting of AIS data it could be linked to the inherent corruption levels of the reporting countries, the Corruption Perception Index (CPI, transparency.org), which captures the level of national public sector corruption perceived by their citizens, was used as a comparable measure of this corruption and willing misreporting by proxy.

5.2.1.3) Fishing hours.

Considering that, in a worst-case scenario, the rounding to the nearest kilometre would lead to vessels only ever accounted for one distance out of two, only a subset of the vessels with an observation ratio of at least 0.5 was retained for further analysis (N = 19018, Fig 5.2). For each gear and engine power class categories in the subset, the average number of Days at sea at distance X was fitted to a Gamma distribution-based generalised additive model (GAM) and the fishing hours per day fitted to a logarithmic model (Appendixes 6 and 7). The average maximum distance at which the vessels were observed was determined for each category of vessel.

Two models to estimate the 'real average' fishing hours of each vessel in the raw AIS data were developed:

- Model A: The maximum distance to the shore reached by a vessel is unchanged with regards to AIS data. The average fishing hours are estimated based on the fits given in Appendix 7.
- Model B: The maximum distance to the shore reached by a vessel is approximated as being the Average Maximum Distance of the vessel category. The average fishing hours (per day) and days at sea (per year) were reconstructed following the fit previously described (Appendix 6)

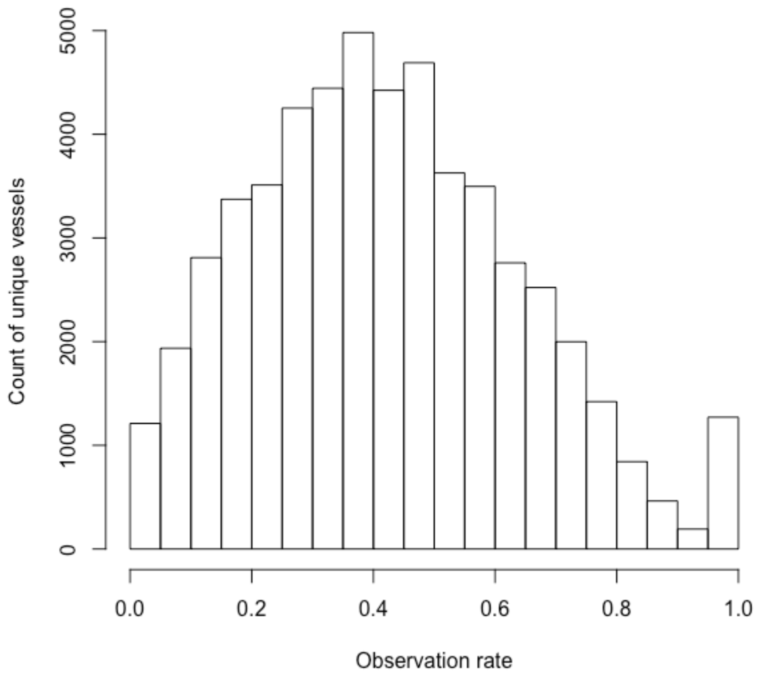


Figure 5.2. Count of vessels by observation rate, 2016 Global Fishing Watch data. The observation rate was defined as the ratio of number of kilometres points at which an individual vessel was observed to the maximum distance at which the vessel was observed.

5.2.2) Mapping effort data.

5.2.2.1) Association of effort and gears.

While the fishing effort data (Rousseau, Watson, Blanchard & Fulton, 2019b) was categorised by engine power categories, comparing it with catch data (Watson, 2019) requires gear association. For each power category, the ratio of different types of gear to the total number of vessels was extracted from various sources:

a) Tuna Regional Fisheries Management Organisations (RFMOs).

The historical fishing fleet data from various RFMOs was extracted from their respective websites:

- Western & central Pacific Fisheries Commission Record of Fishing Vessels (www.wcpfc.int). The data contains historical values, vessel specifications (gears, engine power and gross tonnage) and targeted species by International Radio Call Sign (IRCS) and International Maritime Organisation (IMO) number.
- Indian Ocean Tuna Commission record of Authorised Vessels (www.iotc.org). The data contains historical values, vessel specifications by IRCS.
- International Commission for the Conservation of the Atlantic Tuna Record of vessels (www.iccat.int). The data contains historical values (active and inactive vessels), vessel specifications and targeted species by IRCS and IMO. The active fleet data further indicates the year of construction of the vessels.
- The Consolidated List of Authorised Vessels (clav.iotc.org). The data contains historical values, vessel specifications by IRCS and IMO from various RFMOs.

Only vessels targeting tuna, tuna-like and billfish species were considered “tuna fleet” in these datasets. All databases were cross-compared through individual vessel identification codes (either IRCS, IMO number or commission-specific identifier) and duplicates removed. When no construction year was found for a vessel, a random value was given based on a normal probability distribution of the year of construction of vessels of similar engine power, gross tonnage and flag. When no start of activity was found (vessels built prior to the RMFOs), the year of construction was considered the year of first activity. Only three specific types of gears were kept from the data, purse seine, longlines and poles and lines, all for tuna. As tuna RFMOs give very detailed account of the number of vessels in their management areas and the tuna fishing fleet of the world are traditionally separated from other types of vessels, the gear association for tuna-specific vessels was done prior to associating a ratio of gears to power class. This was done to avoid double counting in specific gears such as longlines and purse seines.

b) Country- specific gears and international data.

The ratio of gear of fleets from Europe, Japan, China, India, Morocco, Taiwan, USA, Canada and Southeast Asia was found in various databases and literature. The sources are indicated in Appendix 3 (Rousseau, Watson, Blanchard & Fulton, 2019b). The FAO databases further provided partial information on the fishing gear associated with vessels for some countries. The ratio of each gear was interpolated with a GAM fitting between year of first and last data and extrapolated by a sigmoidal function outside of these values, as per Rousseau, Watson, Blanchard & Fulton (2019b), to bound values between 0 and 1. When no data was available, similar countries were used as an indication of the ratio of various gears to the artisanal and industrial fleets.

The fishing gears associated with the unpowered fleet, with very few exceptions (most notably Japan), was rarely recorded. To avoid skewing the gear association towards the few countries with information, the ratio of each gear was given as the average ratio of the lowest powered vessels. While this might lead to underestimates of certain hand-gears and overestimates of trawl-types, it was argued that it would be preferable over extrapolating the poorest-countries fleet from developed ones.

The capacity database was separated into 12 categories of gears: hooks and lines (non-tuna, including jigging, handlines and longlines), pole and lines (tuna), longlines (tuna), purse seine (tuna and non-tuna), trawlers, seines, gillnets, liftnets, dredges, pots and traps and other gears. Trawls were further separated as bottom trawls and midwater trawls. With the exception of trawling, which was separated based on the proportion of their respective catch (average of the independent catch database (Watson, 2019) and the Sea Around Us seaaroundus.org data), the capacity data was gear-associated independently from associations provided in the catch database to avoid a gear association biased towards the catch of active fleets and underestimating less efficient gears and vessels. The tonnage of each power class was given by the average value found in the various databases, by year and country.

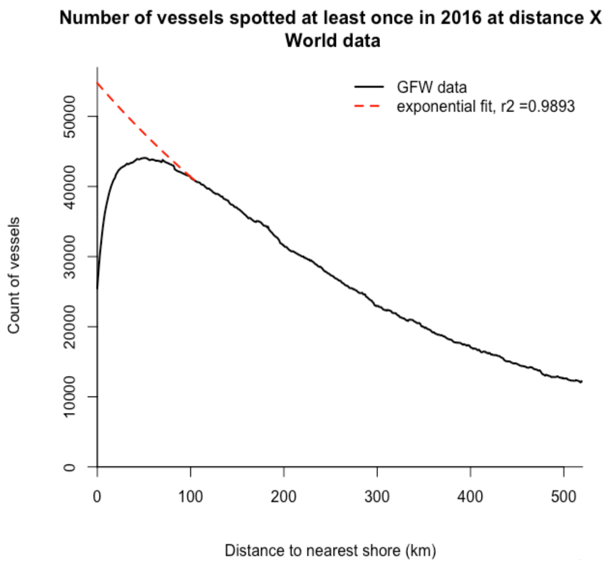
5.2.2.2) Mapping the effort.

The number of days at sea of each power category and gear was extrapolated from existing metadata (Anticamara et al., 2011). To allow for later comparison with the Global Fishing Watch's AIS data, the mapping of the gear-associated fishing effort was carried out independently from their effort, linking instead to a catch ID (event) of the independent landings database (Watson, 2019) based on the gear. When the gear used in the effort did not match any of the gear associations in the catch database then broader gear families were used (e.g. nets encompassing gillnets, liftnets and seines), considering that some errors are possible in the classification due to misnomers, translation of terms and difficulty to determine one specific gear from another (such as troll lines and longlines).

The catch of each event was prorated according to the total gross tonnage of each power class, assuming that a vessel will try to maximise the efficiency of the trip. Each event was then prorated over various 0.5-degree cell, as given by the catch database, prorated on the ratio of the total catch of a category of a vessel by the total engine power for each cell. The accessibility of a boat to specific cells was limited by the engine power and the distance to the shore. Unpowered vessels were limited to territorial waters (12nm from the coast), lower engine power to contiguous and semi-free waters (defined as 45 and 70km from the coast, respectively), higher-powered artisanal to the Exclusive Economic Zone of the country (200nm) and industrial vessels were free to navigate the high seas. The effort (in kw•Days at sea) was then converted in fishing hours based on the link between distance and vessel type shown in the AIS data.

5.3) Results.

5.3.1) Gaps in the Global Fishing Watch AIS datasets.



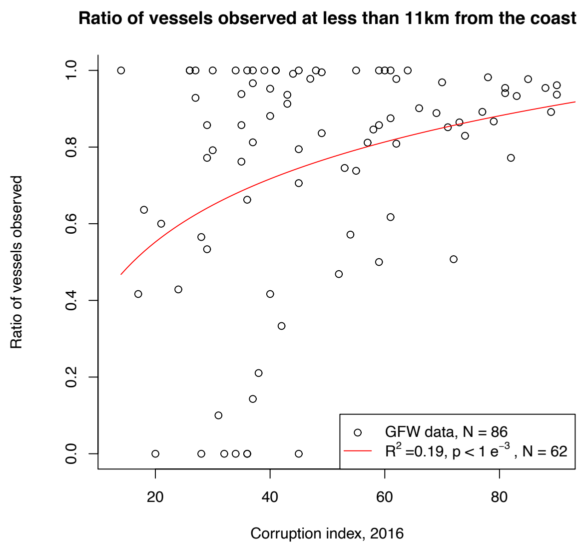


Figure 5.3. Total number of vessels observed at least once at distance X from the nearest shore in the Global Fishing Watch (GFW) data for 2016. The red dotted line represents the expected observation of an exponential decrease of observation with increasing distance.

Figure 5.4. Increasing proportion of undetected vessels compared with increasing perceived corruption, by country. Detection of vessel considered if observed at least once under 11km from the nearest coast, data from Global Fishing Watch (GFW); higher Corruption Index corresponds to lower perceived corruption by nationals, data from transparency.org.

The number of vessels observed at least once during the year at a distance X from the shore was plotted (Fig. 5.3). A discrepancy between the maximum number of vessels observed, 44,076 at 51km from the shore, and a theoretical fit, based on the assumption that no vessel can be observed at a distance X from the shore without being observed at distance X-1, can be demonstrated (Fig 5.3), indicating a vast number of vessels (~10,000) not emitting identification signals at any given time. As the 1km-resolution, however, is higher than the resolution used by the Global Fishing Watch (1/10th degree cell, or approximately 11km at equator), no definite conclusion can be drawn on the total number of vessels not emitting AIS signal. A weakly logarithmic correlation between the ratio of vessels observed at 11km from the coast and the Corruption Index by country, however, was observed (Fig. 5.4), indicative of a link between corruption and broadcasting vessel identification signals.

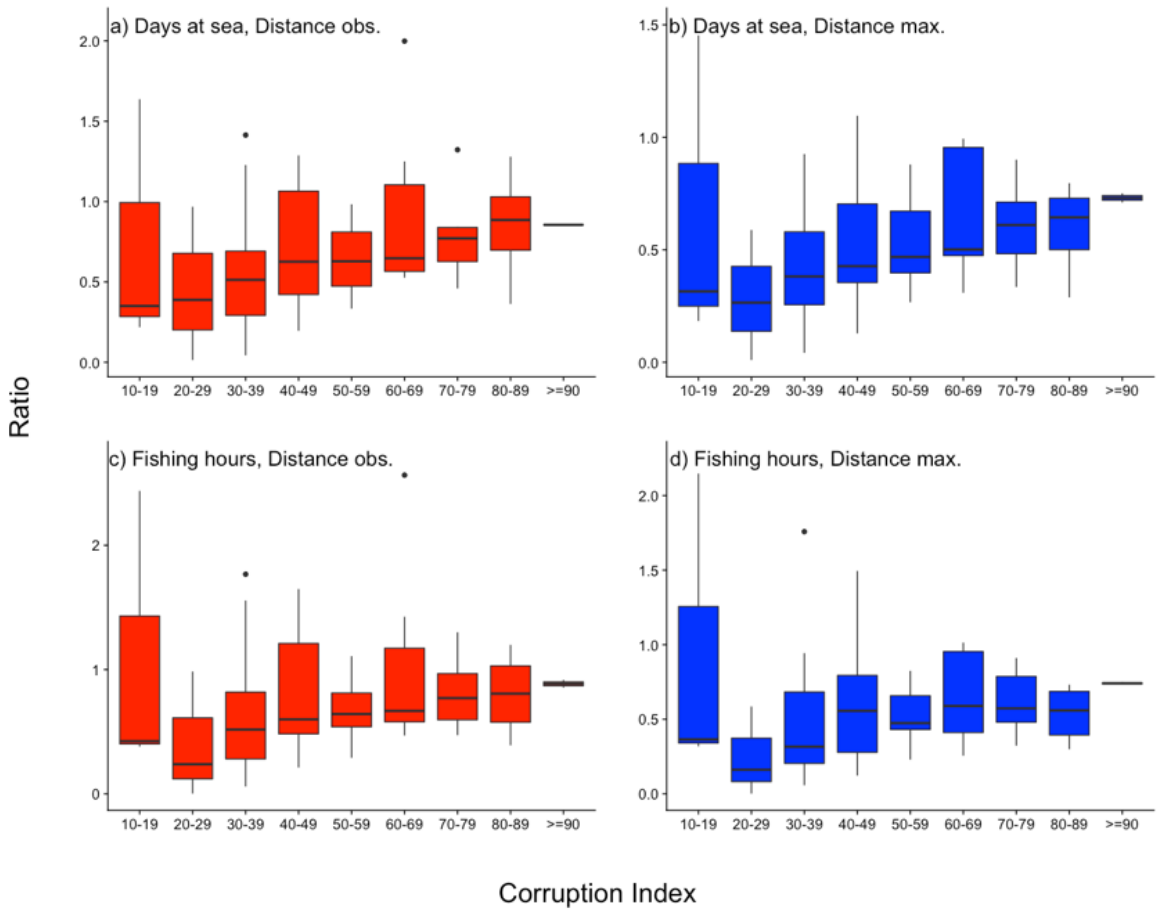


Figure 5.5. Ratio of GFW estimates to modelled days at sea (a and b) and fishing hours (c and d), by perceived corruption index, 2016 data. Left column (a and c) model assumes unchanged maximum observed distance of vessels, right column (b and d) model assumes the maximum distance reached by a vessel based on averages by engine power classes and gear. Please note that high CPI corresponds to low levels of perceived corruption.

Clear relationships were found between the ratio of reconstructed fishing hours to the estimates of the Global Fishing Watch's AIS data (Fig. 5.5), although the results for the lowest category of Corruption Index (highest perceived corruption) might not be significant, due to a low representation of vessels in the data. These results could both indicate that the AIS coverage is lower along the coast due to technical capabilities (Kroodsma et al., 2018), or that in fact 'switching off' AIS signal is wide-spread in countries with high corruption. Due to the link between development index and corruption, however, no attempt to disentangle the cause and effect was made.

5.3.2) Comparison of the AIS data and fishing effort.

Only the 2016 Global Fishing Watch's AIS data was utilised, as 2012 to 2015 was considered a calibration dataset (Kroodsma et al., 2018). The time series of global fishing effort, however, ended in 2015, making a comparison of this last year the most appropriate between the two datasets.

Out of 70,000 vessels used in the AIS dataset, 57,753 fishing vessels could be associated with fishing hours and MMSI records, corresponding with 2.2%, 27.3 % and 16.6 % of the global marine fishing capacity in terms of number of vessels, gross tonnage and total engine power, respectively (Table 5.1). As recognised in their methods (Kroodsma et al., 2018), Global Fishing Watch's AIS data is biased towards the larger, industrial vessels, with vessels over 200kW representing over 77% of their data, and corresponding to 32.5% of the global capacity (in number of vessels). While the effort data was not categorised by the length of vessels, an empirical formula (Anticamara et al., 2011) was used to link vessels of 24m and 12m to a total engine power of 260kW and 66kW respectively. AIS data accounted for approximatively 34.1%, 65.7% and 38.9% of the vessels over 24m and 4.1%, 13.6% and 6.6% of the vessels between 12 and 24m in number of vessels, gross tonnage and engine power respectively, relative to the 2015 global effort data.

While the AIS dataset totals over 40M fishing hours, 'only' 37M could be associated with specific vessels. Considering that only a small portion of the total fishing effort is given in their vessel data, the results were scaled up to match the global estimates of vessels (Table 5.1), extrapolating close to 1B fishing hours for 2016. This contrasts sharply with the estimated 4.16B fishing hours in 2015 in the catch-based effort (Table 5.1), with an even greater difference when considering the unpowered fleet, which added an extra 1.87B hours.

Table 5.1. Number of marine vessels and their characteristics, fishing hours and total days at sea, by engine power class, derived from 2016 processed satellite data (globalfishwatch.org, left column) and 2015 effort data ((Rousseau, Watson, Blanchard & Fulton, 2019b)**, right column), including (top line) and excluding (bottom line) Chinese fishing fleet.**

	AIS data (by MMSI, excluding support vessels), 2016							Effort data (excluding unpowered and support), 2015						
	<20kW	20-50kW	50-100kW	100-200kW	200-500kW	>500kW	Total	<20kW	20-50kW	50-100kW	100-200kW	200-500kW	>500kW	Total
Number of vessels	4	103	1071	8733	34313	10529	54753	1072194	774586	274358	223043	105671	21634	2471486
Tonnage (x1000GT)	<1	4	28	347	3182	5750	93109	2692	3067	3743	7634	7792	9219	341467
Total Engine power (GW)	<1	4	86	1391	11139	11670	24289	11097	27651	19340	32183	31541	24238	146048
Number of countries	3	12	26	47	80	92	100	100	125	125	121	125	115	152
Average day at sea per vessel	39.7	46.3	63.6	60.6	52.1	91.6	61	203.1	199.6	203.1	205.1	199.3	202.8	202
Total fishing hours (Million)	0	0	0.4	3.9	19	14.1	37.5	-	-	-	-	-	-	-
Average fishing hour per DAS	10.02	7.53	6.29	7.4	10.63	14.62	11.17	-	-	-	-	-	-	-
Average distance of first observation	1	2	1	2	6	49	16	-	-	-	-	-	-	-
Modeled total fishing hours (Million)	0	0.1	0.6	7.8	45.5	33.7	87.8	1698.4	1210.4	459.2	475	252.9	64.9	4160.8
Lower 95% confidence	0	0	0.3	6.1	36	29.6	72	1105.6	830.1	354.5	436.7	240.1	61.1	3028.2
Higher 95% confidence	0	0.2	1	9.4	55.1	37.8	103.5	2291.2	1590.7	563.9	513.2	265.7	68.6	5293.5
Modeled average DAS per vessel	187	90.4	92.5	114.4	120.8	210.4	136.4	-	-	-	-	-	-	-
Lower 95% confidence	161.4	39.5	48.8	91	97.6	182.6	111.8	-	-	-	-	-	-	-
Higher 95% confidence	212.7	141.3	136.1	137.8	144.1	238.1	161	-	-	-	-	-	-	-

	AIS data, 2016, China removed							Effort data, 2015, China removed						
	<20kW	20-50kW	50-100kW	100-200kW	200-500kW	>500kW	Total	<20kW	20-50kW	50-100kW	100-200kW	200-500kW	>500kW	Total
Number of vessels	4	101	744	3280	9556	6460	20145	980597	740283	259079	193175	92105	19196	2284435
Tonnage (x1000GT)	0	4	22	122	821	4404	53738	2215	2249	2582	3765	5076	7783	236702
Total Engine power (GW)	0	4	59	504	3076	8663	12305	10123	26603	18120	27242	27329	22110	131527
Number of countries	3	11	25	46	79	91	100	99	124	124	120	124	114	151
Average day at sea per vessel	39.7	45.8	68.7	78.3	83.9	115.3	92	203.5	199.7	203.5	206.3	199.8	203.6	202
Total fishing hours (Million)	0	0	0.4	1.9	8.7	11.3	22.3	-	-	-	-	-	-	-
Average fishing hour per DAS	10.02	7.67	6.86	7.58	10.87	15.17	12.02	-	-	-	-	-	-	-
Average distance of first observation	1	3	1	1	8	47		-	-	-	-	-	-	-
Modeled total fishing hours (Million)	0	0.1	0.4	2.7	12.9	23.2	39.4	1549.7	1158.1	436.9	408.1	218.2	56.9	3828
Lower 95% confidence	0	0	0.2	2.1	9.9	20.6	32.8	1012.1	799.1	336.1	375.6	207.2	53.6	2783.8
Higher 95% confidence	0	0.2	0.7	3.4	15.9	25.8	45.9	2087.4	1517	537.7	440.7	229.3	60.1	4872.3
Modeled average DAS per vessel	187	90.9	92.8	111.4	126.3	231.8	156.3	-	-	-	-	-	-	-
Lower 95% confidence	161.4	40	49.5	84.7	99.1	204.3	128.4	-	-	-	-	-	-	-
Higher 95% confidence	212.7	141.9	136.1	138.2	153.6	259.4	184.3	-	-	-	-	-	-	-

While considering the estimates of fishing hours based on model B, the difference lessens. The model gives results closer to 87.8M, which can then be scaled up, with the aforementioned proportionality rule, to 4.09B, in agreement with the findings of this study. The average time at sea per vessel given in the AIS data is also comparatively lower than the effort data, 61 days compared with 202, respectively. Even remodelled data indicates an estimate of 136 days at sea per vessel, but which was extremely variable by engine power category (Table 5.1).

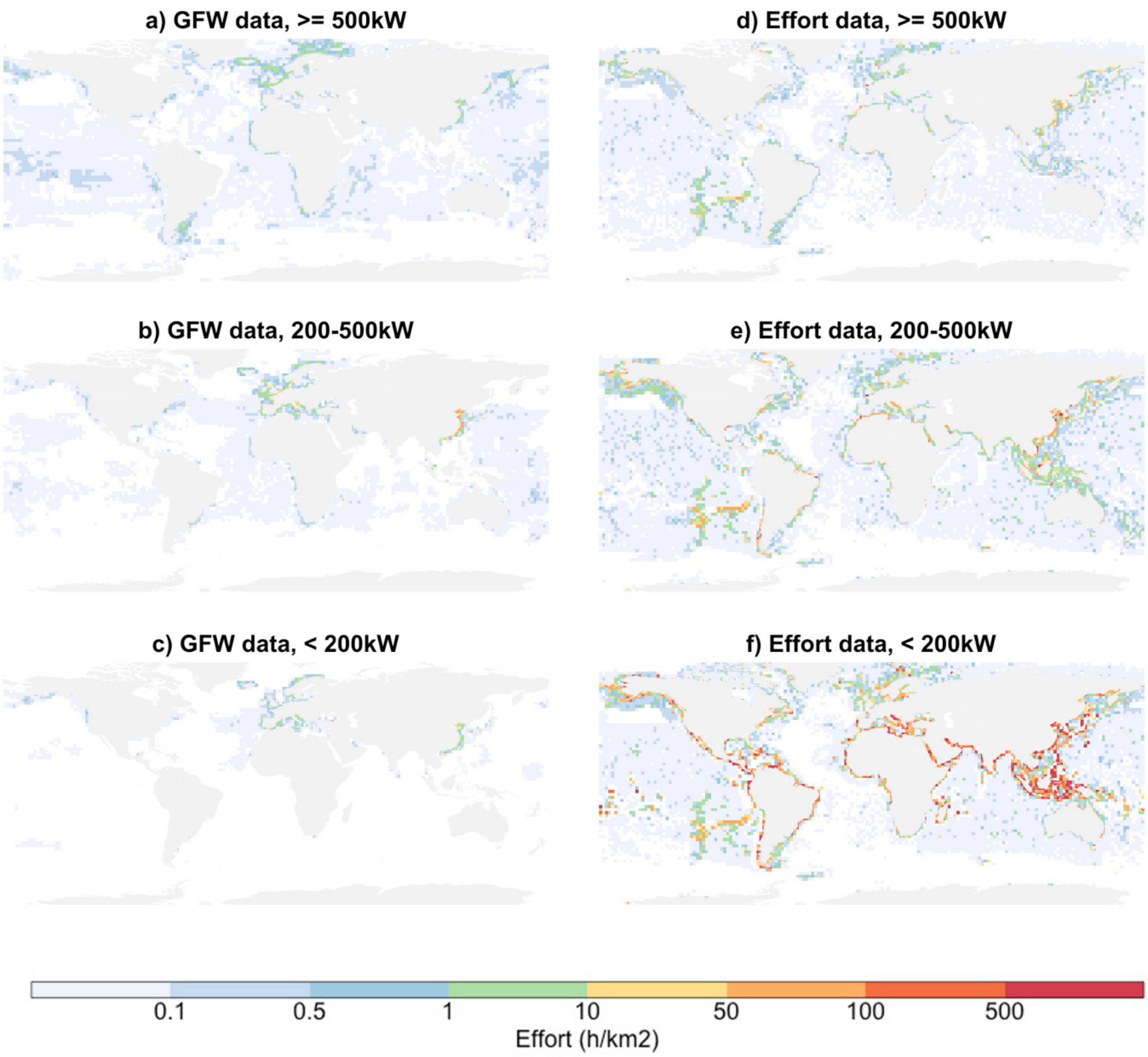


Figure 5.6. Fishing effort, in hours per km2 of sea, by engine power classes, from 2016 Global Fishing Watch (GFW) data (left, a-c) and the mapped effort derived from Rousseau, Watson, Blanchard & Fulton (2019b) (right, d-f).

A comparison of the maps of the Global Fishing Watch's AIS data (2016) and the effort data (2015) shows some similarities in the higher power classes of vessels (Fig. 5.6) In particular, fishing hours in Northeast Asia, Europe and North America show similar location patterns, although the intensity of the fishing shown in the AIS data is lower than the effort (converted from days at sea to fishing hours with model B) for vessels 200kW and higher. Some areas not covered by the AIS data nonetheless present high fishing effort. Southeast Asia and the South Pacific area off the coast of Chile and Peru, in particular, present high levels of effort in the catch-based mapping, but minimal values in the AIS dataset.

Conversely, mapping the effort based on the catch leads to patchier patterns of exploitation on the high seas compared with the mapping of AIS data, and did not match their levels of exploitation along the African coast, particularly with higher powered vessels. Due to the lack of AIS data for lower classes of vessels, the corresponding map showed low fished hours, while the catch-based mapped effort showed intense activity, especially along the coasts.

5.3.3) Spatial development of global fishing fleets.

The expansion of the fishing effort since the 1950s has varied, both geographically and in terms of intensity (Appendix 8). In 1950s, intense fishing effort was seen along the coasts of North American, Europe and Northeast Asia, with pockets of high effort observed close to Japan, Korea, China, the USA and Canada, and discretely in European gulfs. These geographical patterns remained similar throughout the 1960s, with increased intensity of the effort in these regions, combined with 'new players' in South American and Southeast Asia. Intense fishing effort became widespread in the 1970s and 80s, particularly in Southeast Asia. By 2015, most of the world's coast was subjected to high intensity fishing, although lower levels and sparser in Sub-Saharan Africa and Australia. While still high, the fishing effort in North America and Europe declined by 2015 relative to the 1990s. The fishing effort further expanded away from the coasts since the 1960s, particularly in the high seas of the Pacific and Eastern Indian oceans, where fishing effort levels were 10-100 times higher than observed in the Atlantic in 2015.

Some sectorial differences can be observed, both geographically and temporally:

5.3.3.1) Unpowered fishing effort.

Since the 1950s, the fishing effort from the unmotorized fleet has been disparate (Fig 5.7). Throughout the decades, the effort of various countries and regions followed patterns of intensification followed by decline and disappearance. While it was already past its peak intensity in the 1950s in Europe, North America or Australia, the effort from that sector had almost disappeared in these regions by 2015. Meanwhile, unmotorized fleets in Northeast Asia, which presented high intensity effort in the 1950s, decreased vastly throughout the 1960s to reach quasi insignificant levels in 2000 and later.

With the exception of the Philippines, where unmotorized effort remained strong in 2015, a similar pattern is observed in Southeast Asia, delayed by 10-20 years. While non-negligible in 2015, the sectoral effort was only a fraction of what is had been in the 1970s and 80s. Relatively few regions retained high levels of unmotorized effort in 2015, such as the Sub-Saharan coastlines, and patchier exploitation in Central America and the Indian peninsula.

5.3.3.2) Artisanal (motorised) effort.

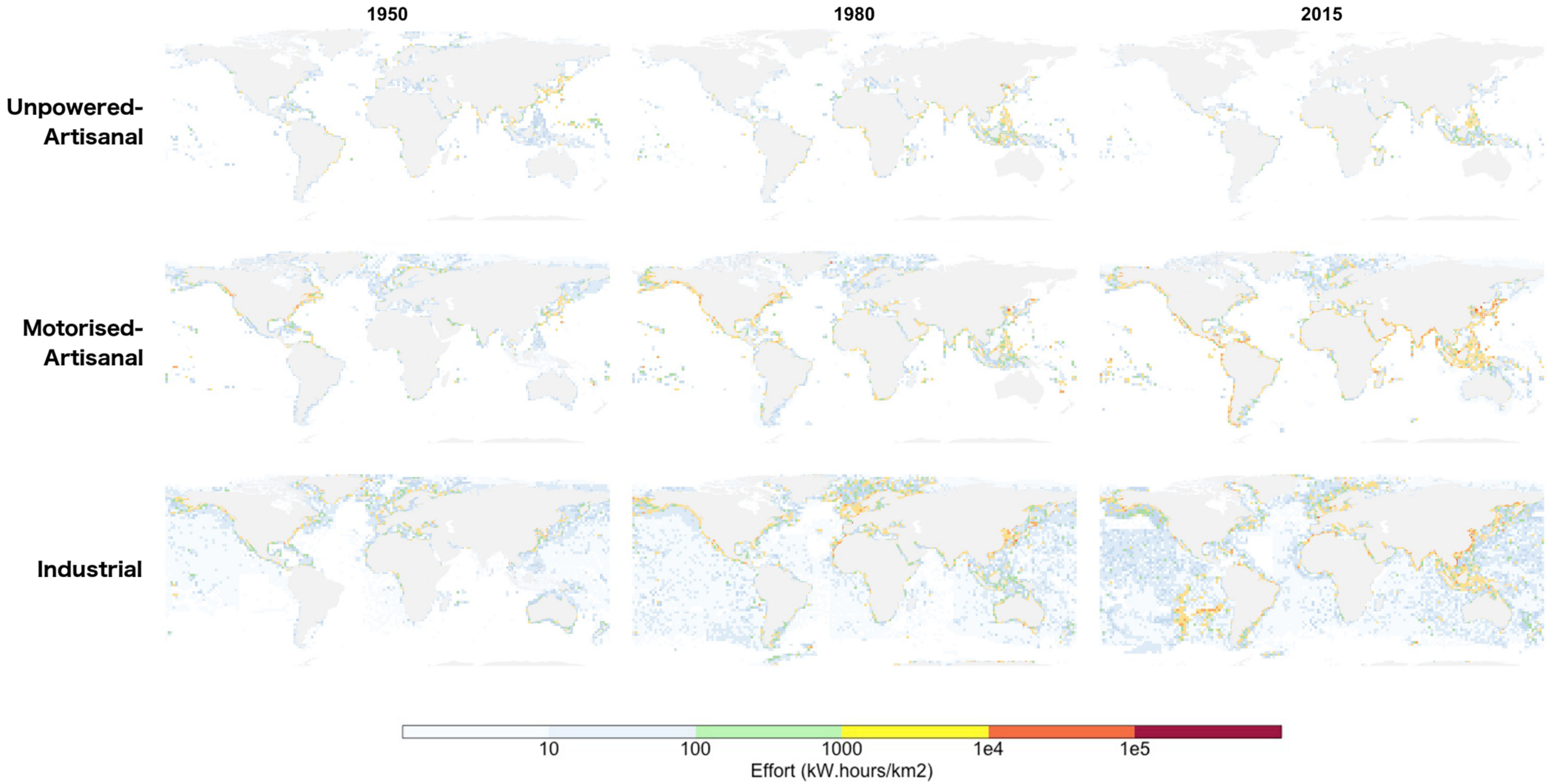
While high intensity artisanal (motorised) fishing was limited to specific countries such as Japan, Canada and the USA in 1950, a few other regions, notably Europe and Mexico presented wider-spread effort (Fig 5.7). With the exception of Sub-Saharan Africa, where it remained low in 2015, the levels of motorised artisanal effort increased steadily over the second part of the 20th century. Some geographical differences in this increase could be observed, such as the dramatic increase in effort in Southeast Asia and Central America in the 2000s, while the Indian peninsula saw that increase in later years.

The Artisanal effort remained mostly coastal globally, with a few exceptions, such as Northern Europe where the effort spread over the Northeast Atlantic, and in Southeast Asia, where the relatively short distance between islands and atolls led to a widespread effort in the region. Some pockets of exploitation were shown in the Southeast Pacific Ocean since the 1990s.

5.3.3.3) Industrial effort.

While the industrial effort was present in locations similar to that of the artisanal effort in 1950s, contrary to the latter it was never limited to the near shore areas. A rapid expansion in the 1960s and 70s was observed throughout the waters of Europe, North America and Northeast Asia, while the effort increased slowly in the coastal waters of the rest of Asia in the 1980s followed by dramatic growth in the 2000s. At the same time, the effort in the high seas increased steadily from 1950 to 2000 and remained relatively constant since. Intense pockets of exploitation in the South Pacific off the Chilean coast have been observed since the 2000s.

While the vast majority of the world’s industrial effort has increased steadily since the 1950s, a few major fishing nations – such as the USA and Canada – have shown reduction and dispersal, leading to fewer pockets of high intensity effort. Similar patterns were observed in the North Sea. Sub-Saharan African levels of industrial effort remained low in 2015, a rather unique exception in the world’s oceans.



2324

2325 **Figure 5.7: Evolution of the mapped fishing effort, in kW-hours per km2, by fishing sector and year.**

5.4) Discussion.

While recent development in the use of AIS data for fisheries management shows promising results, the method is not (yet) a panacea for estimating fishing effort and is bound to its own limits and uncertainties. Similarly, catch-base effort estimation remains a very useful tool, but would gain from integration with more technological tools.

5.4.1) Compatibility of datasets and results.

While mapping the fishing effort based on reported catch gave patterns similar to that observed with the Global Fishing Watch's AIS data, each method presented distinct advantages and drawbacks. AIS data provided high precision, geographically smooth results, and allowed for the mapping of fishing data even when reported catch is lacking (e.g. if misreported). In contrast, the catch-based mapping gave grainer, localised exploitation, limited in its scope to the reported locations of the catch (Watson, 2019). Simply put, a catch-based approach cannot guess locations which have never been reported, and a smoothing factor would need to be added to effort mapped in this way in order to overcome patchiness, at the possible expense of underestimating known pockets of exploitation. Most of the known data used in catch and effort mapping came from very specific datasets, such as the European Union, South East Asia Fisheries Development Center, Tuna RMFOs, … Having used their own records (Watson, 2019) any inconsistencies for the industrial fleet sector are limited, but the artisanal fleets are often data-poor, and as a result some areas might be mis-estimated if not well represented in the aforementioned datasets, especially if the assumptions are not reflective of reality (i.e. if they are over simplifications). This is unfortunately an unavoidable trade-off; and one that is yet unavoidable as satellite geographical systems are a very recent addition to fisheries management tools, making it impossible to use their data to confirm the mapping prior to circa 2010. Catch data has been recorded for decades and so will remain our primary means of looking into the past.

Using catch as a base for mapping the distribution of effort presented some additional difficulties. Perhaps most crucially, catch datasets were also based on extremely-debated extrapolation methods (FAO, 2018), and while they should broadly overlap effort data, some incompatibility is present. Catch maps are themselves models of the catch, and while they allow maps to be constructed for years prior to AIS technology, they do not attain the level of accuracy of pure observation, and probably never will. In addition, gears used in the assignment of effort data might not match perfectly that used in the catch, as the latter is based on gears most commonly associated with species, while the former is a statistical redistribution of the gears reported in country-specific datasets. When provided, countries often report their gears in very broad categories (such as trawlers including Danish seines and dredges) and some uncertainty in translation is present. Names used in gears have important leeway, especially when compiling data from many different cultures and languages. For instance, no standard definition of 'seine' is found in the world, and can include or exclude purse seine or midwater trawls. The final decision is in the hands of the those doing the reconstruction, and while all precautions possible have been taken to limit the uncertainty due to the name of gears, it was often necessary to rely on broader categorisations (such as 'nets' and 'lines') in order to match catch and effort. Multi gearing presented a further challenge. While clearly represented in datasets such as the European fleet register (European Commission, n.d.), it was impossible to know which gear was used by a vessel at a specific time or location; nor was it possible to allocate gears which are not described in datasets. A more dynamic approach, based on the variability of the CPUE, changes in ecosystems and allocated catch, could be employed to reduce this uncertainty, but is well beyond the scope of this study.

Some uncertainty stems from the link between days at sea and fishing hours. While catch-based mapping methodologies allow for the variability of days at sea per annum, taking into account specific events and the change in management from a year to another (Anticamara et al., 2011; Rousseau, Watson, Blanchard & Fulton, 2019b), the number of fished hours per day stems entirely from AIS data and was limited to the most recent years. As such, the (untested) assumption that the number of fished hours per day at sea did not vary temporally was made. Instead, the focus was switched towards the link between engine power and fished hours, with the implied consequence that a temporal change in engine power classes would indirectly affect the average fishing hours of a country.

5.4.2) Corruption in fisheries and its impact on AIS signals.

While AIS data had a definite edge on accuracy compared with catch-based mapping of the effort, some inconsistencies were found. For instance, unlike what has been previously observed (Kroodsma et al., 2018), switching off the satellite signal could be widespread. Up to a quarter of vessels seems to turn off AIS broadcasts at any given time, consistent with previous findings (Shepperson et al., 2018), with the number increasing exponentially closer to the shore[11]. This indicates that both the number of fishing hours and the total number of fishing days was potentially vastly underestimated when based solely on AIS data. In particular, with increased levels of corruption, signalling of specific vessel identity decreased sharply, from approximately 70% to 90% at lower levels of corruption down to 20% at higher levels.

Some of the lower levels of detection of the higher power vessels' AIS signals is not surprising, as it is not uncommon for large vessels, for instance, to (legally) switch off their signals

[11] See https://globalfishingwatch.org/data/going-dark-when-vessels-turn-off-ais-broadcasts/

to avoid letting their exact position be known[12], which would explain why the first observation of higher power vessels is over 40km from the coast (Table 5.1). Furthermore, it is possible that lower levels of detection of AIS signals are in fact due to lack of receiver coverage, especially in the EEZ of less developed countries. A vast portion of the 'hidden fishing hours', however, cannot be explained any other way than vessel captain willingly hiding their identity. These results are of comparable levels as the link between illegal fishing activity and governance (Agnew et al., 2009), and indicate that, even though improvements in detection technology of vessels might help will illegal fishing, they are not a panacea. Low levels of AIS detection seem to be inherently linked to the perceived corruption of a country, whether this corruption is at a monitoring, regulatory or bureaucratic level.

This influence of countries' perceived corruption may have led to biases in the Global Fishing Watch's methodology. It is common in fisheries literature to calibrate models based on a subset of data, often from the European Union (Rousseau, Watson, Blanchard & Fulton, 2019b), due to the availability and details of the data. These countries, however, present amongst the lowest perceived corruption in the world, and might have led to AIS results underestimating the extent of vessels 'going dark'. On the other hand, being aware of this bias, the gaps in AIS reporting could potentially be linked with misreporting in fisheries catch and prove itself a useful tool in measuring the levels of illegal activities.

5.4.3) Gaps in the AIS data.

Using the most 'reliable' subset of the data (i.e. where the AIS signal is the least interrupted), both days at sea and the average fishing hours per day were estimated for a range of gears and

[12] See for instance the safety exception to Australian law https://www.amsa.gov.au/safety-navigation/navigation-systems/requirements-carrying-automatic-identification-system

engine power classes. While the reconstruction vastly reduced the difference between AIS data and the effort data, based on meta-analysis (Anticamara et al., 2011), the number of days at sea extrapolated from AIS data seems comparatively low. This difference could be explained by a number of reasons:

- The number of days at sea close to shore is underestimated. As a subset of the data corresponding to vessels emitting for at least 50% of the locations leading to their maximum known position was used, some vessels which are not plottable for the complete length of their trips could have been included, lowering the overall average days at sea of each category. While the emission rate close to shore for higher-powered vessels (>500kW) is extremely low, the reconstruction gives much higher days at sea than the other categories. This can easily be justified if we consider that larger vessels are more likely to only 'pass by' inshore waters and do not spend much fishing time there, and the few that would switch off their satellite signal close to shore but not in the high seas, would have less effect on the calculation of the corrective models. Since lower-powered vessels, on the other hand, spend a large portion of their fishing time close to shore, it is much more likely that some vessels would be detected at least once over the year but generally do not emit an AIS signal, leading to vast underestimates in their fishing time. This artefact is shown in the remodelled estimates of the AIS data, which decreases significantly with decreasing engine power. An exception to this was found in the lowest power class, although it was considered that the low number of vessels under 20kW cannot significantly represent the class as a whole.

- The number of days at sea in the high seas is underestimated. While logic dictates that a vessel cannot be present in the high seas without having travelled there in the first place, nothing prevents vessels switching off their signal once away from specific management areas (EEZ, RFMOs areas). Since fishing was considered only up to the maximum distance of vessel observation, it is possible that a portion of the high seas fleet was not accounted for. While it makes sense that vessels would not emit identification signals in areas of high piracy, the relatively high average modelled days at sea for higher-powered vessels implies that the practice is neither common nor significant.

- Intermittence of the satellite mission. While the used method of reconstruction takes into account vessels which obviously did not keep their signal on over their entire course, it could not objectively remove all vessels for which there is a doubt in their signal rate, at the expense of reducing the size of the subset of ‘absolutely correct’ data drastically. On the other hand, retaining a larger subset for analysis leads to data being extremely biased towards specific countries, in particular China, whose fleet represents over a third of the AIS dataset but only 8% of the global fleet (Table 1). Some trade-offs were unavoidable due to the quality and extent of the data source.

Due to these factors, it is likely that the average days at sea from AIS data is underestimated. The effect this would have on the total fishing hours is unknown. On one hand an increase in number of days at sea would reduce the average fishing hour per day, but on the other it is likely that the same artefacts would be seen in the total number of fishing hours, balancing itself out. As such, caution is necessary when interpreting AIS data and developing general rules from them. The reconstructed average number of fishing hours per day, however, would be quite robust to these errors, as only the fishing hours of detected vessels can be used, therefore allowing for reconstruction with comparatively lower uncertainty. Satellite data, in this sense, gives a wonderful insight and additional information on the extent of the fishing effort, and while it might become the future of data collection in fisheries, it remains currently beneficial to develop hybrid methods between statistical analysis, meta-analysis and (satellite) data-driven approaches.

5.4.4) Concept of fishing effort and implication for sectoral management.

A common bias in fisheries literature, both science and management, is to minimize the relative effect of artisanal fleets compared with industrial fleets (Rousseau, Watson, Blanchard & Fulton, 2019b). Global Fishing Watch's AIS data perpetuates this view by focusing on the higher power vessels, and as such presents results which are approximately two orders of magnitude lower than the actual extent of the global marine fishing effort. This is particularly true when considering that the AIS data shows a decreasing amount of fishing effort with decreasing engine power. This result is extremely counterintuitive, as one would expect artisanal fishers to spend a large portion of their time at sea (Teh & Sumaila, 2013), unless fishing is a Supplementary activity to their livelihood and not their main source of employment. As the vast proportion of smaller-scale vessels were not equipped with AIS signals, it is necessary to use caution with interpreting results out of the box for the artisanal fleet of the world.

Due to incomplete recording (and thus associated uncertainty) with any available method of estimating effort globally, caution in interpretation is necessary, as the means of defining fishing effort has implications for its interpretation. Using total fishing hours (or days at sea) as a measure of effort, the artisanal effort overshadowed the industrial effort by an order of magnitude (Fig. 5.6), due to the presence of ten times more artisanal vessels than industrial globally. To regain some level of comparability between the two sectors, weighting effort by fishing power (in this case engine power – i.e. fishing hours • kW; Fig. 5.7) gives more insight on the pressure on the oceans' resources. With this measure, we see that the global artisanal fishing effort is almost equal to that of the industrial fleet, but its geographic distribution is vastly different. While the latter is spread over the oceans, the former is concentrated along the coasts, due mostly to limits in engine power and vessel limitations to refrigeration. This leads to a dual issue of competition and fairness. Both sectors potentially compete for the same resources (especially if stocks extend over both areas or are ontogenetically linked between areas) but, as the resource becomes scarce, only the larger scale vessels will be able to expand their fishing grounds, leaving the artisanal fisheries in depleted areas. Furthermore, warming oceans could lead species away from coastal areas, where inshore fleets cannot pursue. Greater focus on the management of fisheries is necessary to avoid such competition-driven gaps in equity and would gain from a better integration of sectorial differences in zoning of fishing areas, such as the ones practiced in Southeast Asia.

5.5) Conclusion.

While future development in AIS datasets might make them the largest and most detailed source of information on tracking marine fishing fleets, their effort and impact, the current and relatively narrow focus on the larger vessels limits their ability to fully represent global fishing effort. Recent insight on the sectorial (artisanal and industrial) disaggregation of global fishing fleets (Rousseau, Watson, Blanchard & Fulton, 2019b), however, coupled with the information extrapolated from AIS data, allows for an expansion of effort mapping to global scales and also presents the opportunity for the first attempt at comparing and cross validating data from both sources. Furthermore, AIS data has been hailed as a solution to monitor illegal, unreported and unregulated activities, and while its coverage is not yet sufficient for this purpose, preliminary analysis of the global data shows a strong link between discrepancies in AIS data and countries' perceived corruption. This link could prove itself a valuable source of information in identifying, analysing and cross-validating misreporting in fisheries data.

Some uncertainties remain, such as the temporal links between days at sea and fished hours, although some implicit variation has been integrated by disaggregating fishing fleets by engine power and gear. The lack of information on the lesser-motorised fleet, which still comprises the major part of global fishing fleet, remains a challenge to be overcome. Standardisation of AIS to even smaller vessels would bring in an invaluable source of information, which has unfortunately not occurred in a meaningfully way yet.

Future steps in mapping the fishing effort would include its validation with more local scale information (Selgrath, Gergel, & Vincent, 2018), integration in global ecosystem models (Galbraith et al., 2017), with feedback loops, to allow for: meaningful calculation of current catch per unit of effort and mortality; as well as consideration of what would be sustainable production levels in different regions and how this compares to food security and nutritional demands(McClanahan, Allison, & Cinner, 2015; Selig et al., 2019). At country level, the catch-independent effort dataset created could prove itself a useful tool for management in data poor fisheries where stock assessments are lacking. To advance this further, removing the use of catch to map the effort requires sharper focus. Having independent estimates is a must for significant advances in confidence over the resulting patterns.

Chapter 6 - General Discussion.

While the idea that the ocean's resources are inexhaustible is long gone, the full extent of the impact of fishing fleets on these resources and the interactions between the two are still not fully understood at a global level. In particular, catch per unit of effort and fishing mortality, two important parameters for both ecosystems and stock assessment models (Chapter 2), remain difficult to estimate. Reports and publications have heavily focused on the industrial fishing fleets and their interactions with the resource, but I have shown (Chapter 4) that the artisanal sector is as impactful, if not more so. Understanding the future of seafood production requires an understanding of both fishing fleets and the marine ecosystems they interact with, and the capacity to integrate them in global models.

6.1) Understanding marine fishing fleets and their impact.

It stands to reason that one cannot understand the future of the global marine fishing fleet without understanding its past and present, which has been the main focus of this thesis. One must warn, however, against falling into the trap of simply extrapolating from past trends, and instead there is a need to understand the links and mechanisms behind fishing fleets.

6.1.1) Descriptive evolution of fishing fleets.

Since the 1950s, the composition and size of the global fishing fleet has evolved considerably, with fewer countries today dominated by an unmotorized fleet, a vast increase in the average engine power of vessels and a wide-spread fleet expansion. Only a handful of countries are showing signs of stabilization of their fleet, mostly in the developed world. Similarly, the end of the expansion of the Chinese fleet, although with mixed results, has gathered intense focus in the news and literature (Cao et al., 2017; Normile, 2017).

Beyond simple numbers of vessels, the average engine power of fishing boats does not show any signs of stabilisation or reduction. It is possible that further evolution of fleets will involve a plateauing of the power per vessel and maybe a reduction similar to that of the fleet size, to reach a more efficient and stable motor power for the catch. There is, however, little to no detectable signs of this yet, amongst a discussion on whether changes in fishing effort is now distinct from changes in catch altogether (Watson et al., 2013).

These variations in the fishing fleets reflect the observed changes in both ecosystems and fisheries management. Access to new fishing grounds has allowed expansion of the global fleets, while local stocks collapses have introduced strict limitations (e.g. of the Peruvian anchoveta). On the management side, supranational entities and international agreements have also vastly affected fishing fleets. For instance, although European countries are at different economic levels, there is a common push from the Union to reduce the fishing fleet, leading to the poorest countries in the block truncating their fleet evolution and capping their peak fleet sizes (EC, 2016). Besides direct management, geopolitical events can be perceived through the study of the fishing fleet. The instability and economic disparity in the Middle East can be seen through various levels of motorisation, with strict policies and management explaining the levelling of the Emirates fleet, while conflicts in other countries have greatly reduced their fishing capacity (Chapter 4). The dissolution of the USSR similarly had a great influence on the fleet in Europe in the early 1990s.

Fishing fleets are obviously both affecting and affected by external parameters such as employment, food security, overfishing, extension of fishing grounds, change in the geopolitical map, etc. Being at the intersection of ecological and societal systems, they are an indicator of the health and failures of these systems, and the evolution of the fleet follows closely the narrative of changes in socioecological systems.

6.1.2) Fishing fleets and the carrying capacity of the oceans

From the fleet reconstruction of Chapter 4 it can be deduced that, as the modern economies of countries develop their fishing fleets, they go through successive phases of motorization, expansion and modernization. These phases can be separated into five conceptual Stages (Fig. 6.1):

- Subsistence (Stage 1): In the infancy of the country's fisheries, the methods are relatively primitive, and scale-limited. The fishing fleet is almost exclusively unpowered, coastal, and population dictates the growth of the fleet.

- Motorization (Stage 2): The unpowered fleet increases and peaks, motorized boats (retrofitting) and small inboard motor vessels appear and increase in numbers.

- Transition/Expansion (Stage 3): The number of unpowered vessels sharply decreases, with a move to powered vessels. Motorization of the artisanal fleet usually peaks, and the number of industrial vessels increase.

- Limitation (Stage 4): The number of vessels in the motorized fleet peaks, the proportion of industrial vessels increase.

- Stabilization and Modernization (Stage 5): The number of motorized vessels decreases and reaches stability. The engine power of individual vessels, however, keeps on increasing.

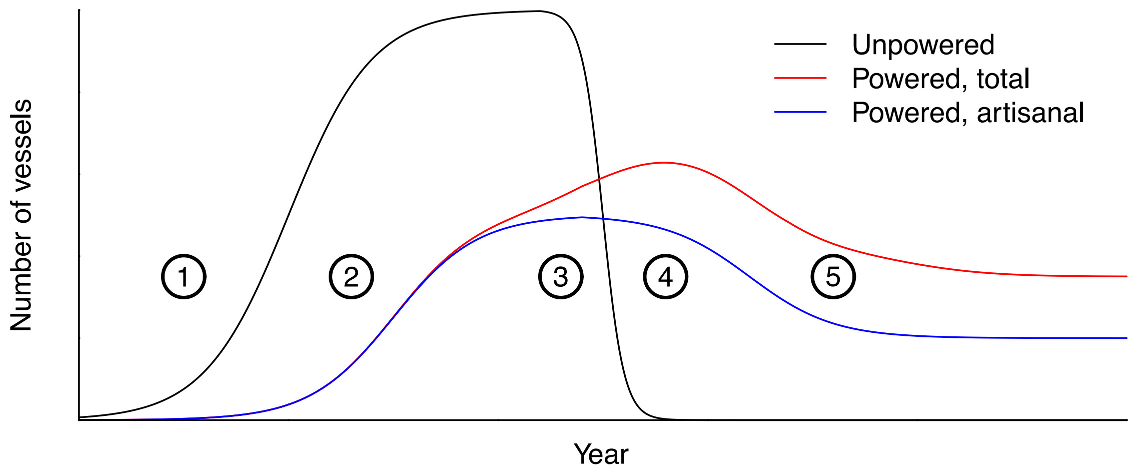


Figure 6.1. Conceptual representation of the motorization of the fishing fleet of a given country.

In the infancy of the motorisation of the fleet, the consumption of seafood landed is limited to local markets and fishing grounds remain coastal, while fully motorised vessels, often with processing facilities, allow for distant water fisheries and exports. The motorisation of the fishing fleet allows for expansion beyond coastal areas to the continental shelf and beyond. With motorisation, fisheries pressure on marine ecosystems increases, new stocks (different and more distant and often deeper living species) are fished. The construction materials of boats switch from wood and similar materials to steel, man-made fibres and plastics. As the fishing grounds dominated by more efficient boats, traditional fishing methods might become endangered, with impacts on traditional fishers who cannot make the change (e.g. at least some indigenous populations). The last stages of modernisation have been associated with an increase in management, either due to ecological collapses or in an attempt to avoid them. It is worth noting, though, that this sequence has not played perfectly in all locations, with incremental additions and less losses in some places. For instance, in India, all 3 classes of vessels are found, though spatially separate and targeting different grounds. This may just be a temporal extension of a transition that ultimately plays out in the usual manner, or, based on socioecological and geopolitical interactions beginning to get international attention, it may be that it is diverted into a new pattern – the intentional removal of mechanisation in favour of motorised and unmotorized vessels for cultural reasons. It is, however, premature at this stage to conclude on either possibility.

Strong links can be made between the evolution of fishing fleets, driven by empirical results, and the base theories of ecological economics, i.e. economic growth limited by natural capital. In a similar way to Huxley's classical argument in favour of the inexhaustibility of oceans' resources (Huxley, 1883), some classical economists have stated that nature cannot limit economic growth, as knowledge and technologies allow humans to go beyond the carrying capacity of the Earth (Sagoff, 1995). Even a descriptive look at the changes fishing fleets have gone through, however, contradicts this view. Fishing fleets stand out from classical economic theory in the sense that technology and knowledge do not create a higher, if virtual, carrying capacity to the oceans. In fact, the limit in Natural Capital, the yield of the oceans, that some may say has been reached in the 80s (Watson & Pauly, 2001), would take time before being reflected in the Human Capital, the fishing fleet.

Beside simple observation, from a theoretical standpoint, in the same way than open and unregulated fisheries are considered a textbook example of the Tragedy of the Commons (Scheiber, 2018), it stands to reason that the development of fishing fleets is linked to the oceans' resources. Indeed, considering fishing vessels to be akin to an apex predator, the limit in number of vessels (stage 4 and 5, Fig. 6.1) would follow the carrying capacity of the fished stocks. Unlike predators, however, which would die off when the prey is consumed beyond sustainable levels, human aspects of the fleet, such as subsidies (Sumaila et al., 2008) or relocation push the fleet beyond what is ecologically sustainable on ever larger scale.

6.1.3) Limits to our understanding and the future of the fleet.

The concept of carrying capacity to socioecological systems, of which fisheries belong, is, however, at best ambiguous (Seidl & Tisdell, 1999), unlike that of a pure ecological system which is clearly bound. While the size of the fleet had been shown to be limited by environmental factors, even withdrawing the management and economics layers of complexity, fishing is intrinsically linked to cultural and traditional elements. These are often simplified or represented by rough proxies (Rousseau, Watson, Blanchard, & Fulton, 2019a) and misunderstood, even though there is a global push towards preserving 'intangible heritage' (Bonn, Kendall, & McDonough, 2016).

This presents a great challenge for fleet reconstruction and predicting the future impact of fleets and resources on one another, as studies rarely take into account the switch between sectors, or even the impact of definitions used. While there is contention on the importance of being able to define so-called artisanal fisheries at the global level, especially from a legal perspective (FAO, 2017), the need from a scientific and management perspective is undeniable. At the global level, however, very few studies have even tried to separate these sectors to begin with, and while this thesis has added to the knowledge in that matter, the challenge is ongoing.

More is required to quantify the links between socio-cultural factors and the evolution of fishing fleets beyond simple reconstruction.

The oceans yield depends, at a biological level, not only on the primary productivity, but also all the steps in between, and the added interactions between ecology and management adds a layer of complexity, which is revealed in the 'stages of motorization' of the global fleet. This disconnect between changes in the fishing fleet and in the fished stocks has been observed throughout the globe. As fisheries management is moving towards ecosystem-based management, fleet management has been seen as a pathway to this goal (Gascuel et al., 2012), but lack of understanding of the drivers behind fishing fleets and their interaction render these changes very difficult.The bottom line is that, while countries will reach a peak fishing fleet, the drivers of this occurrence are composite of biology, climate, management, economics, culture and politics. As such, extrapolating the impact between oceans' resources and fishing fleets is, at best, precarious, and integration of the fishing fleets in models is necessary in order to allow for meaningful predictions.

6.2) Understanding the future of the resource: integration of fleet components into models.

While ecosystem and fishing fleet models are often treated separately, one cannot deny their connectivity, and various fishing parameters are necessary to the development of integrated fishing-ecosystems (so called end-to-end) models (Chapter 2). While ecosystem-based management might stem from fishing-fleet based management, the disciplinary genesis of many models (either economics or biology/ecology) means that they often overlook fishing fleets as a link between ecology and human elements.

6.2.1) The importance of feedbacks between fleets and resources.

The biological, economic and social components of models interact and need to be treated with feedback effects on each other, and not separately. Many parameters, such as mortality, depend on the various synergies between the components, and scientists should not create models that look at fisheries from one perspective alone. Many such parameters link fishing fleets with ecosystems. Fishing mortality, in particular, is one of the most important and obvious links. In ecosystem models, landings are almost exclusively used as proxy for mortality, but does not often account for illegal activity (Agnew et al., 2009). At a global level, the previous lack of detail in the artisanal fleet and its underestimation (Rousseau, Watson, Blanchard & Fulton, 2019b) are particularly concerning, as small changes in the effort or the catchability could vastly affect the fishing mortality of entire regions, particularly pronounced in coastal areas (Chapter 5). Ecosystem focused and stock focused models would gain by creating feedback effects between fishing mortality and effort at the global level, as observed in regional scale ones (Fulton, Link, et al., 2011).

The importance of these feedbacks increases as fisheries management evolves. The debate between selective and balanced harvesting (Burgess et al., 2015), for instance, would likely progress through the integration of multiple fleet types into global ecosystem models, to determine the likely trade-offs between human and natural capital. At a global scale, failure to estimate the size of the fishing fleet might have contributed to its improper management and a vast decrease in the ocean's resources (Rousseau, Watson, Blanchard & Fulton, 2019b). Improvement of this aspect is in turn hindered by the lack of knowledge in the human drivers of fleet dynamics. While fisheries science is a complex socio-ecological field, the human effect on fleet evolution is often reduced to demand from population size, with market price used as a proxy (Chapter 2). But while simple supply-demand models can highlight the growth of a fishery, it does little to explain the evolution of the fishing fleets, nor the observed increase in engine power. The approach developed in this thesis is to separate the fleet by sector and use proxies other than simple landings and market values in order to extrapolate some aspects of the fishing fleets. This a step in the right direction, although more work is required to fully understand the effect of human drivers on fishing fleets and, through fishing mortality, on ecosystems.

Feedback effects and interconnectivity between human, economics and ecological parameters, however, are often still lacking at the global scale. As this might result in governance failure, integrating these factors in global models is necessary, particularly through fishing activities. The integration of fishing fleets in global ecosystem models has, however, been hampered by the lack of detail in fishing fleet data at the relevant scales, and in part to a knowledge gap in the drivers of the fleet and their interaction with ecosystem components, which impedes their dynamic integration into models. While this thesis aims to increase the level of detail necessary in our understanding of the fishing fleet in order to facilitate this integration, much work is left to do. The projection of past fishing fleet data into the future implies that the impact of the global fishing fleet on the oceans will continue to exercise pressure on a limited resource, but simple extrapolation is not enough, and might not yield accurate or significant results.

6.2.2) Conclusion: the future of seafood production.

The future of seafood production is the future of the ocean's yield, meaning the evolution of the oceans' resources, the humans wanting to access them, and the interactions between the two. These interactions are mainly represented by the fishing fleets, and not only is a detailed description of the past of fishing fleets necessary to understand the development of these interactions, it opens an outlook to potential futures. Through the development of the fleet, the future of wild seafood production will face increasing challenges. Expanding populations will need to be supported by ocean production. The arrival in the global fleet of 'new' major players, such as China, already plays an important role in the pressure we exercise on the oceans, and it is likely that the development of fleets in other parts of the world will lead to conflict and increased pressure on the oceans. At the same time, aquaculture has been perceived as an alternative to wild catch fisheries, but still requires feeds which increase pressure on both wild catch fisheries (Merino et al., 2012) and agriculture (Froehlich, Runge, Gentry, Gaines, & Halpern, 2018).

While nowadays an adaptation in fisheries management is observed in the so-called 'developed world', married with an understanding that the oceans' resources are limited, these advances are far from universal and come after a succession of fisheries collapses. The necessities of poverty allow only for limited alternatives, and emerging economies already balancing large population bases and ecosystem stressors are disadvantaged in terms of options for rapid action. The reduction in catch per unit of effort observed in most of the world (Chapter 4) indicates that this scenario of learning through failure might repeat itself, if management of global and national fisheries are not timely and sufficient in scope. Simultaneously, changes in ecosystems due to other drivers, such as climate change, might affect both the location of the fish resources and their composition, and will require further adaptation as it exacerbates resource conflicts.

While observation and understanding of the fishing fleet is a first step, further work is required in order to obtain meaningful predictions of fishing yield. As such, this thesis, by providing the most detailed to data account of the global fishing fleet, is a necessary foundation towards building ecosystem models which allow predictions of the oceans' yield.

Appendixes

Appendix 1 – List of national laws relevant to artisanal fishing.

Country	English translated source/ law (short titles)	Untranslated source (Long titles for laws)	Recr.?	Art.	Small-Scale	Coastal	Subs.	Means	Extent	Topogr.	Use (excl. recr.)	Notes
				Name of Sector(s):				Definition consistent with:				
Albania	Law n 64/2012 on Fishing	Ligj Nr. 64/2012 për Peshkimin	Yes	Yes	Yes	Yes		Yes			Yes	Artisanal, Small-Scale and Coastal considered synonyms and are Commercial (implying a Subsistence Sector)
Algeria	Law 01-11 of 11 Rabie Ethani 1422 corresponding to 3 July 2001 Relative to Fishing and Aquaculture	Loi n 01-11 du 11 Rabie Ethani 1422 correspondant au 3 juillet 2001 Relative a la Pêche et a l'Aquaculture	Yes	Yes						Yes	Yes	Artisanal fishing is commercial, implying a Subsistence Sector.
Angola	Law 6-A/04 of 8 October on Resources Biologiques Aquatiques	Lei n 6-A/04 de 8 de Outubro dos Recursos Biologicos Aquaticos	Yes	Yes			Yes	Yes	Yes		Yes	Industrial fishing refers to the extend of the investment.
Antigua and Barbuda	The Fisheries Act, 2006		Yes									Commercial, Recreational and Sport fishing are referred to but not defined.
Argentina	Resolution 3/2000 on Reglementing the Exercise of Artisanal Marine Fishing Law 24.922 Federal Regime on Fishing Law No 244 on Fishing	Resolución 3/2000 Reglaméntase el ejercicio de la Pesca Artesanal Marítima Ley 24.922 Regimen Federal de pesca Ley no 244 de Pesca	Yes	Yes		Yes	Yes	Yes		Yes	Yes	Coastal (lit. "in view of the coast") might be a subset of Artisanal. Subsistence lit. called "domestic".
Australia	The Fisheries Management Act 1991		Yes	Yes	Yes		Yes				?	Artisanal, Subsistence and Small-Scale referred to but not defined at national level. Some State law define Aboriginal fishing, with a limitation on the use (e.g. the Fisheries Management Act, 2007 of South Australia)
Bahamas	The Fisheries Resources (Jurisdiction and Conservation) (Flats Fishing) Regulations, 2017		Yes			Yes	Yes			Yes	Yes	Coastal and Subsistence are called "flats fishing", which includes Recreational.
Bahrain	Legislative Decree No. 20 of 2002 Regulating the Fishing, Exploitation and Protection of Marine Living Resources	رسوم بقانون رقم (20) لسنة 2002 بشأن تنظيم صيد واستغلال وحماية الثروة البحرية	No									No reference to sectors can be found in the national law.
Bangladesh	The Marine Fishery Ordinance, 1983 MOFL (2017)		Yes	Yes				Yes				- Ministry document: Yearbook of Fisheries Statistics of Bangladesh 2015-16 (2017). Dhaka (Bangladesh), Department of Fisheries, Bangladesh. Ministry of Fisheries and Livestock. Implies that Artisanal is all but trawl fishing.
Barbados	The Fisheries Act (1993) MARD (2003)		Yes		Yes							- Ministry document: Barbados Fisheries management plan 2004-2006 (2003). Oistins (Barbados), Fisheries Division, Ministry of Agriculture and Rural Development. Refers to Small-Scale without defining it.
Belgium	Regulation (EU) 508/2014 Regulation (EU) 2015/523		Yes		Yes	Yes	Yes	Yes				EU Regulations considered in place of national law. Small-Scale Coastal fishing is consistent with means of fishing. Subsistence is found in texts (e.g. 2011/443/EU) but not defined, as it might only be with regards to international agreements. Recreational fishing includes non-commercial but without reference to subsistence.
Belize	The High Seas Fishing Act (Revised 2003). The Fisheries Act (Revised 2000)		Yes		Yes							Commercial and Small-Scale referred to but not defined.
Benin	Law 2014-19 of 07 August 2014 Relative to Fishing and Aquaculture	Loi-cadre n° 2014-19 du 07 aout 2014 Relative à la Pêche et à l'Aquaculture en République du Bénin	Yes	Yes								Artisanal referred to but not defined.

Appendix 1 – List of national laws relevant to artisanal fishing (Cont.)

Country	English translated source/ law (short titles)	Untranslated source (Long titles for laws)	Recr.?	Name of Sector(s): Art.	Small-Scale	Coastal	Subs.	Definition consistent with: Means	Extent	Topogr.	Use (excl. recr.)	Notes
Bosnia and Herzegovina	2012 Law on Fisheries	2012 Закона о Рибарству	Yes								Yes	The law defines Commercial as being for profit, implying restriction on a subsistence (although not referred to).
Brazil	Law no 11.959 of 29 June 2009 on Fisheries and Aquaculture	Lei no 11.959 de 29 de Junho de 2009 da Aquicultura e Pesca	Yes	Yes			Yes	Yes		Yes	Yes	While not defining a topography element per se, the law refers to the operational range of the vessels.
Brunei	The Fishery Order, 2009		Yes			Yes		Yes		Yes		The law does not separate fishing with artisanal/Industrial, it allows for the separation of Brunei waters into zones. The ministry put a moratorium in 2008 on vessels > 20GT in zone 1 <3nm.
Bulgaria	Regulation (EU) 508/2014 Regulation (EU) 2015/523		Yes		Yes	Yes	Yes	Yes				EU Regulations considered in place of national law. Small-Scale Coastal fishing is consistent with means of fishing. Subsistence is found in texts (e.g. 2011/443/EU) but not defined, as it might only be with regards to international agreements. Recreational fishing includes non-commercial but without reference to subsistence.
Cambodia	Royal Kram NS/RKM/506/011- Law on Fisheries 2006	Preah Reach Kram NS/RKM/506/011 chbab stei pi cholophl 2006	No		Yes		Yes	Yes	?	Yes	Yes	Small-Scale, Family and Subsistence considered synonyms. The definition refers to "Small-Scale gears" which is undefined in the law but might be given by governmental policies/decrees.
Cameroon	Decree No 2001/546/PM of 30 July 2001	Décret n° 2001/546/PM du 30 juillet 2001 modifiant et complétant certaines dispositions du décret n° 95/413/PM du 20 juin 1995 fixant les modalités d'application du régime de la pêche	Yes	Yes				Yes		Yes		While the Artisanal Sector does not specifies a limit on distance, Semi-Industrial and Industrial do.
Canada	The Fisheries Act (1985)	Also in French: Loi sur les pêches L.R.C. (1985), ch. F-14	Yes									No reference to sectors other than Recreational and Aboriginal can be found in the national law.
Cape Verde	Decree-Law No 53/2005 of 8 August	Decreto-Lei no 53/2005 de 8 de Agosto	Yes	Yes				Yes				
Chile	Law No. 18.892 Law No. 20.187 Law No. 20.256	Ley No 18.892 de 1989 General de Pesca y Acuicultura, cuyo texto refundido, coordinado y sistematizado ha sido fijado por el Decreto No 430. Ley Nº 20.187 - Modifica la Ley General de Pesca y Acuicultura en materia de reemplazo de la inscripción en el Registro de Pesca Artesanal. Ley no 20.256 Establece normas sobre Pesca Recreativa.	Yes	Yes	Yes			Yes				
China	Fisheries Law of the People's Republic of China 1986 (Modified 2004) Regulations on the Fishing Licence Management, 1989	中华人民共和国渔业法的决定 1986 (根据 2004) 渔业捕捞许可证管理办法 1989	No	Yes				Yes		?		Uncertainty on a restriction on the location, as the law exclude demersal trawling.
Colombia	Decree 2256 of 1991	Decreto 2256 de Octubre 4, 1991 por el cual de reglamenta la Ley 13 de 1990	Yes	Yes	Yes		Yes	Yes	Yes		Yes	
Comoros	-	-	No									Although a Fisheries Code seems to have been written in 2015, it is not accessible in the public domain. Other (public) laws refer to the creation of the National Institute for Agriculture, Fishing and Environment (INRAPE) and modalities for foreign vessels.
Congo Dem Rep	Decree 21 Avril 1937 on hunting and fishing	Décret du 21 avril 1937 portant régime de la chasse et de la pêche	No					Yes				Indigenous fishing limits the use of certain gears. No other reference to Artisanal or Subsistence is found.
Congo Rep	Law No 2-2000 of 1st February 2000	Loi no 2 - 2000 du 1er fevrier 2000 portant organisation de la pêche maritime en République du Congo	Yes	Yes				Yes		Yes		
Cook Islands	The Marine Resources Act 2005		Yes	Yes			Yes					Artisanal and Subsistence referred to but not defined.

Appendix 1 – List of national laws relevant to artisanal fishing (Cont.)

Country	English translated source/ law (short titles)	Untranslated source (Long titles for laws)	Recr.?	Name of Sector(s): Art.	Small-Scale	Coastal	Subs.	Definition consistent with: Means	Extent	Topogr.	Use (excl. recr.)	Notes
Costa rica	Law No 8436 on Fishing and Aquaculture	Ley No 8436 de pesca y aquacultura	Yes	Yes	Yes	Yes	Yes	?		Yes	Yes	While Semi-Industrial and Industrial are separated by the gears they are using and the species caught, Artisanal and Small-Scale are by distance to shore. Subsistence (lit. "Domestic") is referred to but not defined, although other Sectors are all specified to be Commercial in scope.
Cote d'Ivoire	Law No 2016-554 of 26 July 2016	Loi No 2016-554 du 26 juillet 2016 Relative a la Pêche et à l'Aquaculture	Yes	Yes			Yes	Yes			Yes	Subsistence might be considered a subset of Artisanal.
Croatia	Regulation (EU) 508/2014 Regulation (EU) 2015/523		Yes		Yes	Yes	Yes	Yes				EU Regulations considered in place of national law. Small-Scale Coastal fishing is consistent with means of fishing. Subsistence is found in texts (e.g. 2011/443/EU) but not defined, as it might only be with regards to international agreements. Recreational fishing includes non-commercial but without reference to subsistence.
Cuba	Decree-Law 164 Regulating FIshing	Decreto-Ley 164 Reglamento de Pesca	Yes				Yes				Yes	Subsistence (lit. "Social") is commercial but for Social needs.
Cyprus	Regulation (EU) 508/2014 Regulation (EU) 2015/523		Yes		Yes	Yes	Yes	Yes				EU Regulations considered in place of national law. Small-Scale Coastal fishing is consistent with means of fishing. Subsistence is found in texts (e.g. 2011/443/EU) but not defined, as it might only be with regards to international agreements. Recreational fishing includes non-commercial but without reference to subsistence.
Denmark	Regulation (EU) 508/2014 Regulation (EU) 2015/523		Yes		Yes	Yes	Yes	Yes				EU Regulations considered in place of national law. Small-Scale Coastal fishing is consistent with means of fishing. Subsistence is found in texts (e.g. 2011/443/EU) but not defined, as it might only be with regards to international agreements. Recreational fishing includes non-commercial but without reference to subsistence.
Djibouti	Law No 187/AN/02/4ème L Fisheries Code	Loi No 187/AN/02/4ème L portant Code des Pêches	Yes	Yes			Yes	Yes		Yes	Yes	While not defining a topography element per se, the law refers to the operational range of the vessels.
Dominica	The Fisheries Act (1987)		Yes									No reference to sectors can be found in the national law.
Dominican Republic	Law No 307-04	Ley No 307-04 que crea el Consejo Dominican de Pesca y Acuicultura (CODOPESCA)	Yes	Yes			Yes			Yes		Artisanal and Subsistence referred to but not defined. A 54nm zone is reserved for the sectors.
Ecuador	Law on Fishing and Development of Fisheries, Code 2005-007	Ley de Pesca y Desarrollo Pesquero, Codificación 2005-007	Yes	Yes				Yes			Yes	
Egypt	Act No. 124 of 1983 on Fishing, Aquatic Life and Aquaculture	ون رقم 124 لسنة 1983م بشأن الأسماك والأحياء المائية وتنظيم المزارع السمكية	No					?				While no sector is defined, trawls are explicitely referred to.
El Salvador	Decree No 637	Decreto No 637 Ley General de Ordenación y Promoción de Pesca y Acuicultura	Yes	Yes	Yes		Yes	Yes	Yes		Yes	Artisanal and Small-Scale considered synonyms. Extent limited by the number of boats.
Equatorial Guinea	Law No 10/2.003 of 17 November 2003	Ley Núm. 10/2.003 de fecha 17 de Noviembre Reguladora de la Actividad Pesquera en la República de Guinea Ecuatorial	Yes	Yes			Yes	Yes			Yes	Although "minor means" in the law could be understood as extent, the reference to gears suggests means.
Eritrea	The Fisheries Proclamation No 176/2014		Yes	Yes				Yes				
Estonia	Regulation (EU) 508/2014 Regulation (EU) 2015/523		Yes		Yes	Yes	Yes	Yes				EU Regulations considered in place of national law. Small-Scale Coastal fishing is consistent with means of fishing. Subsistence is found in texts (e.g. 2011/443/EU) but not defined, as it might only be with regards to international agreements. Recreational fishing includes non-commercial but without reference to subsistence.

Appendix 1 – List of national laws relevant to artisanal fishing (Cont.)

Country	English translated source/ law (short titles)	Untranslated source (Long titles for laws)	Recr.?	Name of Sector(s): Art.	Small-Scale	Coastal	Subs.	Definition consistent with: Means	Extent	Topogr.	Use (excl. recr.)	Notes
Faroe Islands	Law 28 of 10 March 1994 (Amended by Law 120 of 18 August 2017)	Løgtingslóg nr. 28 frá 10. mars 1994 um vinnuligan fiskiskap, sum seinast broytt við løgtingslóg nr. 120 frá 18. august 2017	?		Yes	Yes		Yes		Yes		A description of the law (in English) can be found in Løkkegaard J., Andersen J.L., Boje J., Frost H.S. & Hovgård H. (2007) Report on the Faroese fisheries regulation: the Faroe model. Copenhagen: Department of Economics, University of Copenhagen. "Small Coastal" is considered to refer to both Small-Scale and Coastal
Fiji	Offshore Fisheries Management Decree 2012		Yes	Yes	Yes		Yes	?				Artisanal, Subsistence and Small-Scale referred to but not defined. The Maritime (Fiji Small craft Code) Regulations 2014 imply that are small vessels any vessel under 14m.
Finland	Regulation (EU) 508/2014 Regulation (EU) 2015/523		Yes		Yes	Yes	Yes	Yes				EU Regulations considered in place of national law. Small-Scale Coastal fishing is consistent with means of fishing. Subsistence is found in texts (e.g. 2011/443/EU) but not defined, as it might only be with regards to international agreements. Recreational fishing includes non-commercial but without reference to subsistence.
France	Regulation (EU) 508/2014 Regulation (EU) 2015/523		Yes		Yes	Yes	Yes	Yes				EU Regulations considered in place of national law. Small-Scale Coastal fishing is consistent with means of fishing. Subsistence is found in texts (e.g. 2011/443/EU) but not defined, as it might only be with regards to international agreements. Recreational fishing includes non-commercial but without reference to subsistence.
Gabon	Law 015/2005	Loi 015/2005 portant Code des pêches et de l'aquaculture en République Gabonaise	Yes	Yes			Yes	Yes	Yes	?	Yes	Although subsistence is practiced by communities "close to water", we considered it as a limitation on land, not at sea. The extent is limited by the investment.
Gambia	The Fisheries Act, 2007		Yes	Yes			Yes	Yes		Yes	Yes	
Georgia	Decree No. 423 of 31 December 2013	დადგენილება №423 2013 წლის 31 დეკემბერი. თევზჭერისა და თევზის მარაგის დაცვის ტექნიკური რეგლამენტის დამტკიცების თაობაზე	Yes			Yes				Yes		
Germany	Regulation (EU) 508/2014 Regulation (EU) 2015/523		Yes		Yes	Yes	Yes	Yes				EU Regulations considered in place of national law. Small-Scale Coastal fishing is consistent with means of fishing. Subsistence is found in texts (e.g. 2011/443/EU) but not defined, as it might only be with regards to international agreements. Recreational fishing includes non-commercial but without reference to subsistence.
Ghana	The Fisheries Act, 2002		Yes	Yes			Yes	Yes				Artisanall and Subsistence referred to but not defined, although it is heavily implied that only canoes are considered.
Greece	Regulation (EU) 508/2014 Regulation (EU) 2015/523		Yes		Yes	Yes	Yes	Yes				EU Regulations considered in place of national law. Small-Scale Coastal fishing is consistent with means of fishing. Subsistence is found in texts (e.g. 2011/443/EU) but not defined, as it might only be with regards to international agreements. Recreational fishing includes non-commercial but without reference to subsistence.
Greenland	The Fishery Act No 18 of 1996	Landstingslov nr. 18 af 31. oktober 1996 om fiskeri	Yes			Yes		Yes		Yes	?	Specificities of the Act are given by Greenland Statistics (www.stat.gl). The law refers to "non-Commercial" without precision on Sport or subsistence.
Grenada	Grenada Fisheries Act 1986 Fisheries Regulations 1987		Yes	Yes								Artisanal is referred to but not defined.
Guatemala	Decree No 80-2002	Decreto Numero 80-2002, Ley General de Pesca y Acuicultura	Yes	Yes	Yes		Yes	Yes			Yes	Many sectors are referred to, all but Subsistence defined by the boat size.
Guinea	Law No 2015/026/AN	Loi No 2015/026/AN Portant Code de la Pêche Maritime	Yes	Yes			Yes	Yes			Yes	

Appendix 1 – List of national laws relevant to artisanal fishing (Cont.)

Country	English translated source/ law (short titles)	Untranslated source (Long titles for laws)	Recr.?	Name of Sector(s): Art.	Small-Scale	Coastal	Subs.	Definition consistent with: Means	Extent	Topogr.	Use (excl. recr.)	Notes
Guinea-Bissau	Decree-Law No 10/2011	Decreto Lei No 10/2011 de 7 de Junho	Yes	Yes			Yes	Yes		?	Yes	<12nm is reserved for Artisanal fishing, although nothing in the law opposes an Artisanal boat to fish beyond this limit.
Guyana	The Fisheries Act (2002)		Yes									The law only refers to Commercial fishing, without defining it.
Haiti	Decree reglementing right of fishing (1978)	Décret règlementant l'Exercice du droit de pêche en Haiti, et subordonnant les particuliers étrangers, sociétés et coopérative, à l'autorisation d'un permis (ou licence) délivré par la Secrétairerie d'État de l'Agriculture des Resources Naturelles et du Développement Rural (1978)	Yes	Yes			Yes	Yes	Yes	Yes	Yes	Industrial fishing refers to the scale of the industry. While not defining a topography element per se, the law refers to the operational range of the vessels.
Honduras	Decree 106-2015, Law General om Fishing	Decreto No 106-2015, Ley General de Pesca	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	The word Small-Scale is not given to a sector per se but implied by a Large Scale sector. The Artisanal Sector has limits on the number of boats.
Iceland	The Fisheries Management Act 116 of 2006	Lög nr. 116/2006, um stjórn fiskveiða, með síðari breytingum.	No					Yes				While not referred to in the law, the Icelandic quota system operates on the Tonnage of the vessel. See fiskistofa.is.
India	MoA (2004)		No	Yes	Yes		Yes	Yes			Yes	Ministry document: Comprehensive Marine Fishing Policy (2004). New Delhi (India), Ministry of Agriculture, Department of Animal Husbandry & Dairying. Subsistence is referred to but not defined.
Indonesia	RI Law No 45 Year 2009	RI Law No 45 Year 2009, dated October 29, 2009 (Amendment to law No 31 Year 2004 Concerning Fishery)	No		Yes		Yes	Yes			Yes	"Minor fisherman' are considered to refer to Small-Scale and Subsistence.
Iran	Regulations relative to artisanal fishing in the Persian Gulf (1984) Regulations relative to fishing in the Oman Sea (1984)		No					Yes				The original text could not be found in Farsi. A Traditional sector is present, only defined as using "traditional gears".
Iraq	Law No 48 of 1976	قانون رقم (48) لسنة 1976م بتنظيم استغلال وحماية الأحياء المائية	No	Yes				Yes				Artisanal is referred to but not defined per se, although implied with motors < 100hp.
Ireland	Regulation (EU) 508/2014 Regulation (EU) 2015/523		Yes		Yes	Yes	Yes	Yes				EU Regulations considered in place of national law. Small-Scale Coastal fishing is consistent with means of fishing. Subsistence is found in texts (e.g. 2011/443/EU) but not defined, as it might only be with regards to international agreements. Recreational fishing includes non-commercial but without reference to subsistence.
Israel	The Fisheries Ordinance 1937	פקודת הדיג, 1937	No			Yes		Yes				Implemented by Fisheries rules 1937 (2000)
Italy	Regulation (EU) 508/2014 Regulation (EU) 2015/523		Yes		Yes	Yes	Yes	Yes				EU Regulations considered in place of national law. Small-Scale Coastal fishing is consistent with means of fishing. Subsistence is found in texts (e.g. 2011/443/EU) but not defined, as it might only be with regards to international agreements. Recreational fishing includes non-commercial but without reference to subsistence.
Jamaica	The Fishing Industry Act (1975) MoA (MICAF) 2008		Yes	Yes	Yes		Yes	Yes		Yes		The law doesn't refer to any sector. Ministry document (Draft): Draft Fisheries Policy (2008). Kingston (Jamaica), Ministry of Agriculture and Lands Fisheries Division (Ministry Of Industry, Commerce, Agriculture And Fisheries). Artisanal and Subsistence are referred to but in a descriptive way. Small-Scale is referred to, without indication of whether it is another name or a different sector.
Japan	The Fisheries Act No 267 of 1949 The Fisheries Basic Act No 89 of 2001 MAFF 2016	漁業法 (昭和二十四年十二月十五日法律第二百六十七号) この水産基本法 (平成十七年七月二十九日法律第八十九号まで゛の改正) -	Yes		Yes	Yes		Yes				- - Ministry document: Fisheries census 2013 (2016). Tokyo (Japan), Ministry of Agriculture, Forestry and Fisheries. Small-Scale and Medium-Scale considered synonyms. The policy and laws give contradicting definitions of Coastal.

Appendix 1 – List of national laws relevant to artisanal fishing (Cont.)

				Name of Sector(s):				Definition consistent with:				
Country	English translated source/ law (short titles)	Untranslated source (Long titles for laws)	Recr.?	Art.	Small-Scale	Coastal	Subs.	Means	Extent	Topogr.	Use (excl. recr.)	Notes
Jordan	Law No 25 for the Organization of Fishing, 1943 Agriculture Law No 13 of 2015	انون صيد الأسماك رقم (25) الصادر في 2 كانون الاول (ديسمبر) لسنة 1943م انون الزراعة رقم (13) لسنة 2014	No									No reference to sectors can be found in the national law.
Kenya	The Fisheries Management and Development Act, 2016		Yes	Yes	Yes	Yes		Yes			Yes	Artisanal is considered to synonymous to both Small-Scale and Subsistence.
Kiribati	The Fisheries Act 2010 MFMRD 2012		Yes	Yes	Yes		Yes					- Ministry document: Kiribati National Fisheries Policy 2013-2025 (2013). Bairiki (Kiribati), Ministry of Fisheries and Marine Resources Development. Artisanal and Small-Scale considered synonyms. Both and Subsistence referred to but no defined.
Democratic People's Republic of Korea	The Fisheries Act (1995, Amended 1999)		No		Yes							The original text could not be found in Korean. Small-Scale referred to but not defined.
Republic of Korea	The Fisheries Act (2009 Amended 2015)	수산업법전문개정 2009. 4. 22 법률 제 9626 호(개정2015. 6. 22 법률 제 13385 호)	Yes			Yes		Yes		?		While implied by sector names (Coastal, Demarcated, Inshore, Deep Sea), no referrence to the topography is found in the law, besides "distant fishing waters" used to describe the Deep Sea Sector.
Kuwait	Law No 46 of 1980	قانون رقم (46) لسنة 1980م بشأن المحافظة على الموارد السمكية	No		?			Yes				The law refers to "small vessels", without further precision.
Latvia	Regulation (EU) 508/2014 Regulation (EU) 2015/523		Yes		Yes	Yes	Yes	Yes				EU Regulations considered in place of national law. Small-Scale Coastal fishing is consistent with means of fishing. Subsistence is found in texts (e.g. 2011/443/EU) but not defined, as it might only be with regards to international agreements. Recreational fishing includes non-commercial but without reference to subsistence.
Lebanon	Resolution No. 255/1 of 1995 Majdalani 2005	قرار رقم 255/1 لسنة 1995م بتنظيم معاهد رياضة الصيد غوصاًتجت الماء -	Yes	Yes								- Majdalani, S. (2005) Census of Lebanese Fishing Vessels and Fishing Facilities. Ministry of Agriculture, Directorate of Rural Development and Natural Resources, Department of Fisheries and Wildlife. Artisanal is referred to but not defined.
Liberia	The Fisheries Regulations 2010		Yes	Yes	Yes		Yes	Yes	Yes	Yes	Yes	
Libya	Law No 8 of 1962 Resolution No 71 of 1990	قانون تنظيم صيد الاسماك رقم (8) لسنة 1962م رار اللجنة الشعبية العامة للثروة البحرية رقم 71 لسنة 1990 م بشأن اصدار للائحة التنفيذية للقانون رقم 14 لسنة 1989 م بشأن استغلال الثروة البحرية.	Yes	Yes								Artisanal is referred to but not defined.
Lithuania	Regulation (EU) 508/2014 Regulation (EU) 2015/523		Yes		Yes	Yes	Yes	Yes				EU Regulations considered in place of national law. Small-Scale Coastal fishing is consistent with means of fishing. Subsistence is found in texts (e.g. 2011/443/EU) but not defined, as it might only be with regards to international agreements. Recreational fishing includes non-commercial but without reference to subsistence.
Madagascar	Law 2015-053	Loi No 2015-053 portant Code de la pêche et de l'aquaculture	Yes	Yes	Yes		Yes	Yes			Yes	
Malaysia	The Fisheries Act 1985		Yes					Yes				The sector is referred to as Traditional.
Maldives	The Fisheries Law of Maldives (1987)		?									A Traditional sector is referred to but not defined.
Malta	Regulation (EU) 508/2014 Regulation (EU) 2015/523		Yes		Yes	Yes	Yes	Yes				EU Regulations considered in place of national law. Small-Scale Coastal fishing is consistent with means of fishing. Subsistence is found in texts (e.g. 2011/443/EU) but not defined, as it might only be with regards to international agreements. Recreational fishing includes non-commercial but without reference to subsistence.
Marshall Islands	Marshall Islands Marine Resources Act 1997		Yes	Yes			Yes	Yes		Yes	Yes	

Appendix 1 – List of national laws relevant to artisanal fishing (Cont.)

Country	English translated source/ law (short titles)	Untranslated source (Long titles for laws)	Recr.?	Name of Sector(s): Art.	Small-Scale	Coastal	Subs.	Definition consistent with: Means	Extent	Topogr.	Use (excl. recr.)	Notes
Mauritania	Law No 2015-017 Decree No 2015-159	Loi No 2015-017 du 29 juillet 2015 Portant Code des Pêches Maritimes Décret No 2015-159 Portant application de la Loi No 017-2015 du 29 juillet 2015 Portant Code des Pêches Maritimes	Yes	Yes		Yes	Yes	Yes			Yes	Both Coastal and Artisanal sectors based on technical aspects of vessel and species targetted.
Mauritius	The Fisheries and Marine Resources Act 2007		Yes	Yes								Artisanal is referred to but not defined.
Mexico	Law General DOF 04-06-2015 Norm NOM-029-PESC-2006	Ley General de Pesca y Acuacultura Sustentables 2007 (Amended 2018) Norma Oficial Mexicana NOM-029-PESC-2006: Pesca responsable de tiburones y rayas. Especificaciones para su aprovechamiento	Yes	Yes			Yes	Yes	Yes	Yes	Yes	Subsistence (lit. "Domestic") excludes commercialisation. Extent of Artisanal is referred to as "minor", without further details.
Micronesia	The Marine resources Act of 2002		Yes	Yes		Yes	Yes			Yes		Artisanal is referred to but not defined. Traditional is customary reef fishing and might be included in the Artisanal sector.
Montenegro	Law on Marine Fisheries and Mariculture (2009)		Yes		Yes			Yes			Yes	
Morocco	Dahir 1-97-88 MPM (2014)	Dahir n° 1-97-88 du 23 kaada 1417 (2 avril 1997) portant promulgation de la loi n° 04-97 formant statut des chambres des pêches maritimes (B.O. n° 4470 du 3 avril 1997) -	No	Yes		Yes		Yes				The law doesn't refer to sectors. National fishing fleet (Flotte de pêche nationale). Ministère de l'Agriculture, de la Pêche Maritime, du Développement Rural et des Eaux et Forêts. http://www.mpm.gov.ma, accessed November 2017. The ministry implies a definition of Artisanal and Coastal based on vessel characteristics.
Mozambique	Decree No 43/2003 Fisheries Law 22/2013	Decreto No 43/2003 de 10 Dezembro Lei No 22/2013 de 1 de Novembro de 2013	Yes	Yes			Yes	Yes		Yes	Yes	While not defining a topography element per se, the law refers to the operational range of the vessels.
Myanmar	Myanma Marine Fisheries Law (1990)		Yes			Yes						Coastal (lit. "Inshore") is referred to but not defined.
Namibia	The Marine Resources Act, 2000 The Marine Resources Amendment Act, 2015		Yes								Yes	Recreational includes subsistence. No other sector besides Commercial is referred to.
Nauru	The Fisheries Act 1997		Yes					Yes	Yes	Yes		The law refers to "small boats", in coastal waters, limited by size and without support, which we considered as extent.
Netherlands	Regulation (EU) 508/2014 Regulation (EU) 2015/523		Yes		Yes	Yes	Yes	Yes				EU Regulations considered in place of national law. Small-Scale Coastal fishing is consistent with means of fishing. Subsistence is found in texts (e.g. 2011/443/EU) but not defined, as it might only be with regards to international agreements. Recreational fishing includes non-commercial but without reference to subsistence.
New Zealand	The Fisheries Act 1996 The Maori Fisheries Act 2004		Yes	Yes	Yes		Yes					Artisanal, Small-Scale and Subsistence referred to but not defined. They might refer only to other countries. Commercial fishing is defined by permit, not use.
Nicaragua	Law No 489 of 2004	Ley No 489 de 2004 de Pesca y Acuicultura	Yes	Yes	Yes		Yes	Yes			Yes	Artisanal and Small-Scale considered synonyms.
Nigeria	The Sea Fisheries Act (1992)		No	Yes				Yes		Yes		Artisanal is implied as canoes. Industrial fishing is restricted 5nm from coasts.
Niue	The Domestic Fishing Act 1995 The Domestic Fishing Regulations 1996		No					?				No sector is defined, although licencing doesn't apply to barges and canoes. Species and times are restricted.
Norway	The Marine Living Resources Act (2008)	Lov om forvaltning av viltlevande marine ressursar (havressurslova)	Yes					?				No reference to sectors beyond Recreational can be found in the national law. It is very likely, due to its EEA status, that some limited form of the EU law applies.
Oman	Marine Fishing Law (1981)	قانون الصيد البحري وحماية الثروة المائية الحية	No	?								The law refers to "amateur fishing" but without defining it, it is unclear whether it refers to Artisanal or Recreational.
Pakistan	The Fisheries Act, 1897 The Balochistan Sea Fisheries Ordinance, 1971		Yes					?		?		The national law has not been repealed for over a century. No reference to sectors is found. Example of state law. Sport fishing is defined, no other sector is found, although some restrictions on gears and locations are found.

Appendix 1 – List of national laws relevant to artisanal fishing (Cont.)

				Name of Sector(s):				Definition consistent with:				
Country	English translated source/ law (short titles)	Untranslated source (Long titles for laws)	Recr.?	Art.	Small-Scale	Coastal	Subs.	Means	Extent	Topogr.	Use (excl. recr.)	Notes
Palau	The Marine Protection Act of 1994		No				Yes				Yes	No reference to sectors can be found in the national law. A reference to "livelihood" using non commercial species is found, but remains unclear.
Panama	Resolution No 175 of 2016	Resolución de Gabinete No 175 de 20 de diciembre de 2016 que adopta el Plan Nacional de Acción para la Pesca Sostenible	Yes	Yes			Yes	Yes			Yes	
Papua New Guinea	The Fisheries Management Act 1998		Yes	Yes				Yes	Yes		Yes	Artisanal uses "small scale means", for household and domestic market.
Peru	Decree No 012-2001-PE Decree Law No 25977	Decreto Supremo No 012-2001-PE Aprueban el Reglamento de la Ley General de Pesca Decreto Ley No 25.977 Ley General de Pesca	Yes	Yes	Yes		Yes	Yes			Yes	Artisanal and Small-Scale considered synonyms, with caveats on the techniques.
Philippines	Philippine Fisheries Code of 1998 (Republic Act No. 8550)		Yes	Yes	Yes		?	Yes			Yes	The law refers to Municipal, which could be Subsistence and/or Artisanal. The definition is more consistent with technical aspects (thus we considered it as Artisanal), although it is implied that it might include non-commercial fishing.
Poland	Regulation (EU) 508/2014 Regulation (EU) 2015/523		Yes		Yes	Yes	Yes	Yes				EU Regulations considered in place of national law. Small-Scale Coastal fishing is consistent with means of fishing. Subsistence is found in texts (e.g. 2011/443/EU) but not defined, as it might only be with regards to international agreements. Recreational fishing includes non-commercial but without reference to subsistence.
Portugal	Regulation (EU) 508/2014 Regulation (EU) 2015/523		Yes		Yes	Yes	Yes	Yes				EU Regulations considered in place of national law. Small-Scale Coastal fishing is consistent with means of fishing. Subsistence is found in texts (e.g. 2011/443/EU) but not defined, as it might only be with regards to international agreements. Recreational fishing includes non-commercial but without reference to subsistence.
Qatar	Law No 4 of 1983	قانون رقم (4) لسنة 1983م بشأن استغلال وحماية الموارد البحرية الحية في قطر	No	Yes								Artisanal is referred to but not defined.
Romania	Regulation (EU) 508/2014 Regulation (EU) 2015/523		Yes		Yes	Yes	Yes	Yes				EU Regulations considered in place of national law. Small-Scale Coastal fishing is consistent with means of fishing. Subsistence is found in texts (e.g. 2011/443/EU) but not defined, as it might only be with regards to international agreements. Recreational fishing includes non-commercial but without reference to subsistence.
Russia	Federal Law No 166-FZ (2004)	О рыболовстве и сохранении водных биологических ресурсов Федеральный закон Российской Федерации от 20 декабря 2004 г. N 166-ФЗ	Yes			Yes	?			Yes	Yes	"Coastal Industrial" is referred to, by opposition to Amateur fishing (personal consumption and recreation). Some provision for Indigenous fishing is found in the law.
Saint Kitts and Nevis	The Fisheries, Aquaculture and Marine Resources Act 2016		Yes		Yes		Yes	Yes		Yes	Yes	
Saint Lucia	The Fisheries Act, 1984 The Fisheries Regulations, 1994		Yes									No reference to sectors beyond Sport fishing can be found in the national law.
Saint Vincent and the Grenadines	The Fisheries Act (1986, Amended 1989)		Yes									No reference to sectors beyond Recreational can be found in the national law.
Samoa	The Fisheries Management Act 2016		Yes				Yes					Subsistence and Commercial are referred to but not defined.
Sao Tome and Principe	Decree No. 28/2012	Decreto no 28/2012 Regulamento Geral sobre o Exercísio das Actividades das Pescas e dos Recursos Haliêutico na República Democrática de São Tomé e Príncipe	Yes	Yes			Yes	Yes		Yes	Yes	
Saudi Arabia	Fishing Regulations in Saudi Arabia (undated)	اللائحة التنظيمية لصيد الاسماك في المملكة العربية السعودية	No	Yes				Yes		Yes		

Appendix 1 – List of national laws relevant to artisanal fishing (Cont.)

Country	English translated source/ law (short titles)	Untranslated source (Long titles for laws)	Recr.?	Name of Sector(s): Art.	Small-Scale	Coastal	Subs.	Definition consistent with: Means	Extent	Topogr.	Use (excl. recr.)	Notes
Senegal	Law No 2015-18 Decree No 2016-1804	Loi No 2015-18 du 13 juillet 2015 portant Code de la Pêche maritime Décret 2016-1804 du 22 novembre 2016 portant application de la loi n° 2015-18 du 13 juillet 2015 portant Code de la Pêche maritime	Yes	Yes			Yes	Yes			Yes	
Seychelles	The Fisheries Act, 2014		Yes									No reference to sectors beyond Recreational can be found in the national law.
Sierra Leone	The Fisheries (Management and Development) Decree, 1994		Yes	Yes				Yes				
Singapore	The Fisheries Act (1966, Amended 2002) The Fisheries (Fishing Vessels) Rules (1969, Amended 1992)		Yes					?				The law does not separate fishing in Artisanal/Industrial, but does make the distinction between inboard/outboard motors.
Slovenia	Regulation (EU) 508/2014 Regulation (EU) 2015/523		Yes		Yes	Yes	Yes	Yes				EU Regulations considered in place of national law. Small-Scale Coastal fishing is consistent with means of fishing. Subsistence is found in texts (e.g. 2011/443/EU) but not defined, as it might only be with regards to international agreements. Recreational fishing includes non-commercial but without reference to subsistence.
Solomon Islands	The Fisheries Management Act 2015		Yes	Yes				Yes	Yes	Yes	Yes	The Artisanal sector has the specificities of Small-Scale, Coastal and Subsistence.
Somalia	Somali Fisheries Law (1985, Reviewed 2016)		No					Yes		Yes		Official translation of the Law. A Traditional sector is present.
South Africa	Marine Living Resources Act No 18 of 1998 DAFF 2012		Yes		Yes		Yes	Yes			Yes	- Ministry document: Policy for the Small scale Fisheries Sector in South Africa (2012). Department of Agriculture, Forestry and Fisheries.
Spain	Regulation (EU) 508/2014 Regulation (EU) 2015/523		Yes		Yes	Yes	Yes	Yes				EU Regulations considered in place of national law. Small-Scale Coastal fishing is consistent with means of fishing. Subsistence is found in texts (e.g. 2011/443/EU) but not defined, as it might only be with regards to international agreements. Recreational fishing includes non-commercial but without reference to subsistence.
Sri Lanka	The Fisheries and Aquatic Resources Act, No 2 of 1996 (Amended 2015) Fishing Operations Regulations of 1996		Yes					Yes				A Traditional sector is referred to, implied to be made of specific vessel types.
Sudan	The Marine Fisheries Ordinance (1937) The Marine Fisheries Regulations (1960)	مرسوم الصيد البحري لسنة 1937م اللائحة التنفيذية للصيد البحري	No									No reference to sectors can be found in the national law.
Suriname	The Sea Fisheries Act (1980)	WET van 31 december 1980, houdende regelen op het gebied van de zeevisserij (S.B. 1980 no. 144), gelijk zij luidt na de daarin aangebrachte wijzigingen bij S.B. 2001 no. 120	Yes									No reference to sectors beyond Recreational can be found in the national law.
Sweden	Regulation (EU) 508/2014 Regulation (EU) 2015/523		Yes		Yes	Yes	Yes	Yes				EU Regulations considered in place of national law. Small-Scale Coastal fishing is consistent with means of fishing. Subsistence is found in texts (e.g. 2011/443/EU) but not defined, as it might only be with regards to international agreements. Recreational fishing includes non-commercial but without reference to subsistence.
Syria	Legislative Decree No 30 of 1964	مرسوم تسريعي رقم (30) لسنة 1964م بشأن قانون حماية الأحياء المائية	Yes									No reference to sectors beyond Recreational (lit. Amateur) can be found in the national law.
Taiwan	Fisheries Law (1929, Amended 2016) Fisheries Law enforcement Rules (1930, Amended 2015)	漁業目 漁業法施行細則	Yes			Yes		?		?		No reference to sectors beyond Recreational can be found in the national law. The Fisheries Agency (fa.gov.tw) separates in Coastal and Offshore, and separates into 3/4 categories: unpowered vessels, under 20GT and over 20/100GT.

Appendix 1 – List of national laws relevant to artisanal fishing (Cont.)

Country	English translated source/ law (short titles)	Untranslated source (Long titles for laws)	Recr.?	Name of Sector(s): Art.	Small-Scale	Coastal	Subs.	Definition consistent with: Means	Extent	Topogr.	Use (excl. recr.)	Notes
Tanzania	The Fisheries Act, 2003 The Fisherie Regulations, 2005 The Fisheries Act, 2010		Yes	Yes				Yes	Yes		Yes	The extent is considered thrice by the use of "small scale", limiting the number of vessels to 5 and considering "low investment". Implied limits on vessel length.
Thailand	The Royal Ordinance on Fisheries B.E. 2558 (2015)	พระราชกำหนด การประมง พ.ศ. ๒๕๕๘	No	Yes				Yes		Yes	Yes	Artisanal is in coastal seas and non commercial.
Timor Leste	Decree No 5/2004 Decree-Law No 6/2004	Decreto do Governo No 5/2004 de 21 de Julho Regulamento Geral de Pescas Decreto Lei Governo No 6/2004 Bases Gerais do Regime Jurídico da Gestão e Ordenamento da Pesca e Aquicultura	Yes	Yes	Yes		Yes	Yes		Yes	Yes	Small-Scale include Artisanal, Subsistence and Semi Industrial.
Togo	Law No 2016-026	Loi No 2016 -026 du 11 octobre 2016 portant règlementation de la pêche et de l'aquaculture au Togo	Yes	Yes			Yes	Yes		Yes	Yes	
Tonga	The Fisheries Management Act 2002 The Fisheries (Coastal Communities) Regulations 2009		Yes	Yes			Yes				Yes	Subsistence is dfined but Artisanal is not. Unclear whether the sectors overlap.
Trinidad and Tobago	The Fisheries Act (1916, Amended 2004)		Yes	Yes				Yes		Yes		Artisanal is not well defined. Can operate withing 2nm and include manual trawls.
Tunisia	Fisherman Code (1975) Decree No 95-793 Law No 94-13	Loi No 75-17 du 31 mars 1975, portant promulgation du code pêcheur Décret No 95·793 du 2 mal 1995 réglementant l'encouragement de l'État au profit des petits agrlculteurs et des petits pêcheurs Loi No 94-13 relative a l'exercice de la pêche	Yes		Yes			Yes				Small-Scale is referred to but badly defined. "Small shipowners" refers to vessels <5GT
Turkey	Fishery Regulations 22223 (1995)	Su Ürünleri Yönetmeliği 22223 (10/03/1995)	Yes					Yes				No Sector is defined beyond Recreational, although the law separates vessels in length categories, possibly echoing the 12m of the EU.
Tuvalu	The Marine Resources Act 2006		Yes	Yes			Yes	Yes	Yes	Yes	Yes	
UAE	Federal Law No 23 of 1999	انون اتحادي رقم (23) لسنة 1999 م ي شأن استغلال وحماية وتنمية الثروات لمائية الحية ي دولة الامارات العربية المتحدة	Yes								?	Commercial fishing is referred to but not defined.
Ukraine	Law No 3677-VI	ЗАКОН УКРАИНЫ О рыбном хозяйстве, промышленном рыболовстве и охране водных биоресурсов (Ведомости Верховной Рады Украины (ВВР), 2012, N 17, ст.155) {С изменениями, внесенными Законом N 5462-VI (5462 -17) от 16.10.2012}	Yes				Yes				Yes	The law refers to "amateur fishing", defined as fishing "for personal needs", akin to Subsistence
United_Kingdom	Regulation (EU) 508/2014 Regulation (EU) 2015/523		Yes		Yes	Yes	Yes	Yes				EU Regulations considered in place of national law. Small-Scale Coastal fishing is consistent with means of fishing. Subsistence is found in texts (e.g. 2011/443/EU) but not defined, as it might only be with regards to international agreements. Recreational fishing includes non-commercial but without reference to subsistence.
Uruguay	Law on Fishing 13.833 Decree No 149/997	Ley No 13.833 Riquezas del Mar (Ley de Pesca) Decreto No 149/997 - Actualiza la reglamentación referente a la explotación y dominio sobre riquezas del mar	Yes	Yes				Yes	Yes		Yes	
USA	Fisheries Act of 1995 Magnuson-Stevens Fishery Conservation and Management Act (1976, Amended 2007)		Yes		?			?				The law refers to "small vessels", without further precision.

Appendix 1 – List of national laws relevant to artisanal fishing (Cont.)

Country	English translated source/ law (short titles)	Untranslated source (Long titles for laws)	Recr.?	Name of Sector(s): Art.	Small-Scale	Coastal	Subs.	Definition consistent with: Means	Extent	Topogr.	Use (excl. recr.)	Notes
Vanuatu	Fisheries Act No 10 of 2014		Yes	Yes					Yes	Yes	Yes	
Venezuela	Decree No 1.408/14	Decreto No 1.408/14 Ley de Pesca y Acuicultura	Yes	Yes	Yes		Yes	Yes	Yes	Yes	Yes	Small-Scale is a subset of Artisanal, and low in investment (by opposition to industrial)
Vietnam	Law on Fisheries (2017, EIF 2019) Fisheries Law (2003, Repealed) Ordinance on the Conservation and Management of Living Aquatic Resources 1989		No			Yes						Official translation of the Law. A Traditional sector is present. The Ordinance refers to Offshore, without further definition.
Yemen	Law No 2 of 2006	قانون رقم 2 لسنة 2006م بتنظيم صيد واستغلال الأحياء المائية وحمايتها	No	Yes		Yes		Yes				

Appendix 2 – Table 3.2 (extended) with values represented graphically in Fig. 3.2

6 Ws	Name	parameters	Could also be?	Example of proxy chosen as example in Fig. 3.2	Source	Min. value	Max. value	France	UK	Iceland	Peru	Philippines	Mexico
What	Targetting	Species involved.	When	% of catch (in tonnage) from tuna/anchovies*	seaaroundus.com***	0	100	21.1	13.6	0.2	61.2	34.5	23.2
		Geography	When	% of catch (in tonnage) in EEZ of the country	seaaroundus.com***	0	100	46	48.3	80.3	98.5	95.1	92.9
Where	Location	Distance to shore		NA (implied in EEZ)	-								
		Depth		NA (implied in EEZ)	-								
Why	Purpose	Recreational / Subsistence / Barter / Commercial / Cultural	Who	% of catch (in tonnage) for subsistence	seaaroundus.com***	0	2a	1.4	0	0.7	0.2	0.9	1.7
		Vessel characteristics		Average Gross Tonnage per vessel*	EU fleet register (1), statice.is, produce.gob.pe***	2	100b	26	38	87	22	4	4
	Means	Gear		% of fleet not trawl	EU fleet register (1), statice.is, produce.gob.pe***	0	100	85	76.9	97.1	99.9	98.8	97
How		Motorization		Average Engine Power (kW) per vessel*	EU fleet register (1), statice.is, produce.gob.pe***	0	300b	142	142	277	52	46	19
		Investment	Who	Subsidies per capita (Thousands US dollar)*	(2)	0	25	16.1	17.8	21.5	2.9	0.3	0.2
		Societal impact	Who	% of agriculture/fisheries to GDP	World bank data***	0	15c	1.6	0.6	5.3	6.8	3.1	13.3
	Impact	Environmental impact		% of threatened species in the commercial fisheries*	fishbase.de***	0	20d	14.3	18.7	18.2	3.6	11.7	4
		Extent	What	% of commercial species to total species	fishbase.de***	0	15a	6.1	7.6	7.4	1.8	5.9	14.6
		Day/night time fishing		NA - not relevant at national level	-								
When	Seasonality	Seasonal species/ground	What	NA - not relevant at national level	-								
	Historical	Traditional/Customary	Who/Why	% of indigenous to national population**	iwgia.org***	0	25e	0.3	0	0	12.9	13.6	23.5
Who	Actor	Self determination		% of persons employed in fisheries/agriculture to national population**	(3)	0	3f	0.04	0.03	2.32	0.26	2.69	2.28
		Recognition (community)	When	NA - not relevant at national level	-								

(1) http://ec.europa.eu/fisheries/fleet/index.cfm

(2) Sumaila et al. (2010). A bottom-up re-estimation of global fisheries subsidies. DOI: 10.1007/s10818-010-9091-8

(3) FAO (1999). Number of fishers. FAO Fishing circular FIDI/C929 (Rev.2)

* lower values considered higher level of artisanal

** population data from world bank https://data.worldbank.org/

*** all fleet, catch and employment data for 2014, species 2018, indigenous data 2018, population data of various year corresponding to measured data

Appendix 3 – Extended data sources and definition of “artisanal fishing” used per country in Chapter 4. The processes are detailed in Appendix 4.

Country	Years	Source	Definition of "Artisanal" used.	Process separation A/I/UP/Power	A	I	UP	Includes Power?	Sociocult. region (for analysis)	Sociocult. region (for results)	notes
Albania	1960-1992	(Osmani, Decolli, Ceriola, Ungaro, & Mannini, 2003)	< 12m			x			Europe	Europe	
Albania	1990-2002	(Flloko, 2003)	< 12m			x		Yes	Europe	Europe	
Albania	2003	(Çobani, 2005)	< 12m		x		x		Europe	Europe	
Albania	2001-2007	(INSTAT, n.d.)	< 12m			x			Europe	Europe	
Albania	2015	(EC, 2016)	< 12m		x	x			Europe	Europe	
Algeria	1999-2009	(MPRH, n.d.)	From data: "Petits Métiers"		x	x			Maghreb	Arab World	
Algeria	1965	(FAO, n.d.-d)	inboard/outboard	Algeria a	x	x	x		Maghreb	Arab World	
Algeria	2001-2002 2007-2010	(FAO, n.d.-c)	Trawls, Purse seine, Tuna	Algeria b		x		Yes	Maghreb	Arab World	
Angola	1950 2013	Estimate	NA	Angola a	x				Sub Saharan	Sub Saharan	
Angola	1969	(Medeiros, 2012)	< 14m			x	x		Sub Saharan	Sub Saharan	

Appendix 3 - Extended data sources and definitions used in Chapter 4 (Cont.)

Angola	2001	(Agostinho, Fielding, Sowman, & Bergh, 2005)	From data		x			Yes	Sub Saharan	Sub Saharan	
Angola	1997	(Horemans, 1998)	From data		x		x		Sub Saharan	Sub Saharan	
Angola	1950-1959 1962-1967	(FAO, n.d.-d)	NA	Angola b		x			Sub Saharan	Sub Saharan	
Angola	1995-1996 1999-2000 2008-2009	(FAO, n.d.-b)	< 14m	Angola c	x	x			Sub Saharan	Sub Saharan	
Argentina	1961-1987 1992-1997	(Lasta, Ruarte, & Carozza, 2001)	From data: costal		x				S America	Latin Am.	
Argentina	1961-2000	(Bertolotti, Verazay, Erratzi, Pagaoni, & Buono, 2001)	From data: costal / <18m			x			S America	Latin Am.	
Australia	1950-1978	(ABS, n.d.)	From data: <10m	Australia a	x	x	x		Australia NZ	Oceania	
Australia	1990	(Kailola et al., 1993)	From data: <10m	Australia a	x	x			Australia NZ	Oceania	
Australia	2014	(Flood et al., 2014)	From data: <10m	Australia b	x	x			Australia NZ	Oceania	
Azerbaijan	-	-	-	-	-	-	-	-	-	-	Caspian Sea only
Bahamas	1994	(Deleveaux & Higgs, 1995)	<6m/unregistered	Bahamas a	x	x	x		Caribbeans	Latin Am.	
Bahamas	2012	Estimate	<6m/unregistered			x			Caribbeans	Latin Am.	

Appendix 3 - Extended data sources and definitions used in Chapter 4 (Cont.)

Bahamas		(Moultrie et al., 2016)	NA					Yes	Caribbeans	Latin Am.
Bahrain	1998 2004	(FAO, 2005e)	all but prawn fishery		x				Middle East	Arab World
Bahrain	1983	(Ali & Abahussain, 2013)	all but prawn fishery		x				Middle East	Arab World
Bahrain	1965-1980	(Abdulqader, 1995)	all but prawn fishery			x			Middle East	Arab World
Bangladesh	1973-1999	(Khan & Haque, 2003)	All non trawlers	Bangladesh a	x	x	x		Indian Pen.	Indian Pen. / Asia
Bangladesh	2000-2015	(FRSS, n.d.)	All non trawlers	Bangladesh a	x	x	x		Indian Pen.	Indian Pen. / Asia
Barbados	1950-1960	(Bair, 1962)	< 12m		x		x		Caribbeans	Latin Am.
Barbados	1994-2001	(McConney, Mahon, & Oxenford, 2003)	< 12m		x	x		Yes	Caribbeans	Latin Am.
Belgium	1950-2015	(European Commission, n.d.)	< 12m and without towed gears.		x	x		Yes	Europe	Europe
Belize	2010	(OSPESCA, 2012)	from data: all not tuna/shark	Belize a	x		x		Centr Am.	Latin Am.
Belize	1996-2011	(Gongora, 2012)	from data: all not tuna/shark	Belize a	x				Centr Am.	Latin Am.
Belize	1966 1988 2001-12	(IOTC, n.d.)	from data: all not tuna/shark	Belize b		x			Centr Am.	Latin Am.
Benin	1965 1970	(Everett, 1976)	From data: pirogues	Benin a	x	x	x		Sub Saharan	Sub Saharan

Appendix 3 - Extended data sources and definitions used in Chapter 4 (Cont.)

Benin	1993 1995 1997	(Horemans, 1998)	From data: pirogues	Benin a	x	x	x		Sub Saharan	Sub Saharan	
Benin	1984	(Weber & Durand, 1986)	From data: pirogues	Benin a	x	x	x		Sub Saharan	Sub Saharan	
Benin	1998	(Gbaguidi & Fiogbe, 1999)	From data: pirogues	Benin a	x		x	Yes	Sub Saharan	Sub Saharan	
Bosnia & Herzegovina	-	-	-	-	-	-	-	-	-	-	Excluded
Brazil	1958 1977	(Dias-Neto, 2010)	From data	Brazil a		x			S America	Latin Am.	
Brazil	2003	(Dias-Neto & Filho, 2003)	From data		x	x			S America	Latin Am.	
Brazil	2005	(Dias-Neto & Dias, 2015)	From data	Brazil b	x	x	x		S America	Latin Am.	
Brazil	1958	(IBGE, 1960)	From data		x				S America	Latin Am.	
Brazil	2009	(SINPESQ, 2009)	From data		x	x			S America	Latin Am.	
Brazil	2001	(FAO, 2001)	From data		x				S America	Latin Am.	
Brunei Darussalam	1976-2012	(SEAFDEC, n.d.)	< 20 GT	SEAFDEC (6)	x	x	x		SE Asia	SE Asia/ Asia	
Bulgaria	1950-2015	(European Commission, n.d.)	< 12m and without towed gears.		x	x		Yes	Europe	Europe	
Cabo Verde	1980	(Lawson & Robinson, 1983)	open decked		x		x		NW Africa	Sub Saharan	
Cabo Verde	1974	(Everett, 1976)	open decked			x			NW Africa	Sub Saharan	

Appendix 3 - Extended data sources and definitions used in Chapter 4 (Cont.)

Cabo Verde	1986-2000	(Rosário Martins, 2002)	open decked		x		x	Yes	NW Africa	Sub Saharan
Cabo Verde	1994-2001	(Tenreiro de Almeida, Correia, de Melo Tavares, Pastor, & Lopes de Barros, 2004)	open decked			x		Yes	NW Africa	Sub Saharan
Cabo Verde	2004-2005	(Oceanic Development, 2010)	open decked		x	x	x		NW Africa	Sub Saharan
Cambodia	1957 1983-1994	(Som, 1999)	From data: < 50hp	Cambodia a	x	x	x	Yes	SE Asia	SE Asia/ Asia
Cambodia	2000-2006	(Puthy, 2007)	From data: < 50hp	Cambodia a	x	x	x	Yes	SE Asia	SE Asia/ Asia
Cambodia	2001	(R Gillett, 2004)	From data: < 50hp	Cambodia a	x	x	x	Yes	SE Asia	SE Asia/ Asia
Cambodia	2009	(UNIDO, FiA, & MAFF, 2015)	From data: < 50hp	Cambodia a	x	x	x	Yes	SE Asia	SE Asia/ Asia
Cameroon	1951-1971	(Laure, 1971)	From data: outboard pirogue			x			Sub Saharan	Sub Saharan
Cameroon	1960-1992	(Kébé, Njock, & Gallène, 1993)	From data: outboard pirogue	Cameroon a	x	x	x	Yes	Sub Saharan	Sub Saharan
Cameroon	1995	(MINEPIA, 2011)	From data: outboard pirogue			x			Sub Saharan	Sub Saharan
Cameroon	1995	(Njifonjou, Folack, Bondja, Njock, & Njamen, 1995)	From data: outboard pirogue		x		x	Yes	Sub Saharan	Sub Saharan
Canada	1951-1965	(FAO, n.d.-d)	Decision: < 20 GT	Canada a	x	x	x		N America	N America
Canada	1985-2015	(DFO, n.d.)	Decision: < 20 GT	Canada b	x	x			N America	N America

Appendix 3 - Extended data sources and definitions used in Chapter 4 (Cont.)

Canada	NA	(Transport Canada, n.d.)	NA	Canada c				Yes	N America	N America
Chile	1950-1952 1955 1962-1967	(FAO, n.d.-d)	< 50 GRT/ <18m	Chile a, Chile b	x	x	x	Yes	S America	Latin Am.
Chile	1991-2012	(SERNAPESCA, n.d.-b)	< 50 GRT/ <18m	Chile b, Chile c	x	x	x		S America	Latin Am.
Chile	1993-2015	(DIRECTEMAR, n.d.)	< 50 GRT/ <18m	Chile b, Chile c	x	x	x		S America	Latin Am.
Chile	NA	(FAO, n.d.-c)	NA	Chile d		x		Yes	S America	Latin Am.
Chile	NA	(SERNAPESCA, n.d.-a)	From data	Chile d				Yes	S America	Latin Am.
China	1979-2015	(Fisheries Administration Bureau, n.d.-a)	Decision (Korea/Japan): <10 GT	China a	x	x	x	Yes	NE Asia	NE Asia/Asia
China	1950-1978	(Fisheries Administration Bureau, n.d.-b)	Decision (Korea/Japan): <10 GT	China a	x	x	x	Yes	NE Asia	NE Asia/Asia
Colombia	1950-1966	(FAO, n.d.-d)	From data: outboard engines	Colombia a	x	x	x		S America	Latin Am.
Colombia	1950	Estimate	-	Colombia b		x			S America	Latin Am.
Colombia	2010 2014	(FAO, 2015a)	From data: outboard engines			x			S America	Latin Am.
Colombia	2015	(Altamar & Zúñiga, 2015)	From data: outboard engines	Colombia c	x			Yes	S America	Latin Am.
Colombia	1994 2006	(CCI, 2006)	From data: outboard engines			x		Yes	S America	Latin Am.

Appendix 3 - Extended data sources and definitions used in Chapter 4 (Cont.)

Comoros	2011	(Mohamed Toihir, 2011)	All: no industrial in the Comoros		x		x		Sub Saharan	Sub Saharan
Congo	1965-1976	(Cayré & Fontana, 1977)	From data: pirogues		x	x	x	Yes	Sub Saharan	Sub Saharan
Congo	1994	(Kébé, Njock, & Gallène, 1995)	From data: pirogues		x	x	x		Sub Saharan	Sub Saharan
Congo, Dem. Rep. of the	1950-2015	(Kahozi, 2002; Weber & Durand, 1986)	NA	DRC a	x				Sub Saharan	Sub Saharan
Congo, Dem. Rep. of the	1965 1974	(Everett, 1976)	NA						Sub Saharan	Sub Saharan
Congo, Dem. Rep. of the	1984	(Weber & Durand, 1986)	NA		x	x	x		Sub Saharan	Sub Saharan
Congo, Dem. Rep. of the	2002	(Kahozi, 2002)	NA			x			Sub Saharan	Sub Saharan
Congo, Dem. Rep. of the	1995	(Breuil & Grima, 2014b)	NA				x		Sub Saharan	Sub Saharan
Cook Islands	1991	(McCoy, 1991)	All not tuna/trawl		x		x		Pacif. Isl.	Oceania
Cook Islands	2001-2005	(WCPFC, 2005)	All not tuna/trawl			x			Pacif. Isl.	Oceania
Cook Islands	2012-2016	(WCPFC, 2017b)	All not tuna/trawl		x	x			Pacif. Isl.	Oceania
Cook Islands	NA	(OFD, 2014)	All not tuna/trawl					Yes	Pacif. Isl.	Oceania
Cook Islands	NA	(WCPFC, n.d.-d)	All not tuna/trawl					Yes	Pacif. Isl.	Oceania
Costa Rica	1986	(Chavarría, 1988)	From data.		x	x			Centr Am.	Latin Am.

Appendix 3 - Extended data sources and definitions used in Chapter 4 (Cont.)

Costa Rica	1997 1999	(Beltrán Turriago, 2001)	From data.		x	x			Centr Am.	Latin Am.
Costa Rica	2000	("Coastal fisheries of Latin America and the Caribbean," 2011)	From data.		x	x			Centr Am.	Latin Am.
Costa Rica	2010	(OSPESCA, 2012)	From data.		x		x	Yes	Centr Am.	Latin Am.
Cote d'Ivoire	1950-1957	(Lassarat, 1958)	pirogues			x			Sub Saharan	Sub Saharan
Cote d'Ivoire	1970 2014	(Failler, El Ayoubi, & Konan, 2014)	pirogues			x			Sub Saharan	Sub Saharan
Cote d'Ivoire	1984	(Weber & Durand, 1986)	pirogues			x			Sub Saharan	Sub Saharan
Cote d'Ivoire	1988-1996	(Kébé, Njock, & Gallène, 1997)	pirogues		x	x		Yes	Sub Saharan	Sub Saharan
Cote d'Ivoire	1997	(Dadi, 1999)	pirogues			x			Sub Saharan	Sub Saharan
Cote d'Ivoire	2004	(FAO, 2008a)	pirogues		x		x		Sub Saharan	Sub Saharan
Cote d'Ivoire	2007 2010	(Koffie-Bikpo, 2010)	pirogues			x			Sub Saharan	Sub Saharan
Cote d'Ivoire	2014	(DAP & UEMOA, 2016)	pirogues		x				Sub Saharan	Sub Saharan
Croatia	1950-2015	(European Commission, n.d.)	< 12m and without towed gears.		x	x		Yes	Europe	Europe
Cuba	1953-1954	(FAO, n.d.-d)	From data	Cuba a	x		x		Caribbeans	Latin Am.
Cuba	2004-2010	(FAO, n.d.-c)	From data	Cuba a	x		x		Caribbeans	Latin Am.

Appendix 3 - Extended data sources and definitions used in Chapter 4 (Cont.)

Cuba	1950	Estimate	-	Cuba b		x			Caribbeans	Latin Am.
Cuba	1970s	(CIA, 1963)	From data	Cuba b		x			Caribbeans	Latin Am.
Cuba	2011	("Coastal fisheries of Latin America and the Caribbean," 2011)	From data		x				Caribbeans	Latin Am.
Cyprus	1950-2015	(European Commission, n.d.)	< 12m and without towed gears.		x	x		Yes	Europe	Europe
Denmark	1950-2015	(European Commission, n.d.)	< 12m and without towed gears.		x	x		Yes	Europe	Europe
Djibouti	1950	Estimate	From data: no industrial ex. 2 trawls	Djibouti a	x	x			Sub Saharan	Sub Saharan
Djibouti	2002	(De Young, 2006)	From data: no industrial ex. 2 trawls		x				Sub Saharan	Sub Saharan
Djibouti	2014	(Breuil & Grima, 2014a)	From data: no industrial ex. 2 trawls	Djibouti b	x	x		Yes	Sub Saharan	Sub Saharan
Dominica	1975	(Lintern, 1978)	From data: no industrial		x		x		Caribbeans	Latin Am.
Dominica	1985	(Goodwin, Orbach, Sandifer, Towle, & Berliner, 1985)	From data: no industrial		x			Yes	Caribbeans	Latin Am.
Dominican Rep.	1991	(Silva & Colom, 1996)	From data		x		x		Caribbeans	Latin Am.
Dominican Rep.	2000	(Mateo & Haughton, 2004)	From data		x		x		Caribbeans	Latin Am.
Dominican Rep.	2003	(García Marín & Durán, 2007)	From data		x		x		Caribbeans	Latin Am.

Appendix 3 - Extended data sources and definitions used in Chapter 4 (Cont.)

Ecuador	1956 1960-1962 1981-1985	(Villar, 1998)	From data	Ecuador a	x	x			Centr Am.	Latin Am.
Ecuador	1953-1963 1967	(FAO, n.d.-d)	NA	Ecuador a		x	x		Centr Am.	Latin Am.
Ecuador	1994-2011	(FAO, n.d.-b)	From data	Ecuador b	x	x	x		Centr Am.	Latin Am.
Ecuador	2007 2009	(FAO, n.d.-c)	From data	Ecuador b		x		Yes	Centr Am.	Latin Am.
Ecuador	1996-2008	(Pinoargote, 2008)	From data	Ecuador b	x	x	x		Centr Am.	Latin Am.
Ecuador	?	(Cedeño, n.d.)	From data	Ecuador b	x		x		Centr Am.	Latin Am.
Ecuador	2013	(Martínez-Ortiz, Aires-Da-silva, Lennert-Cody, & Maunderxs, 2015; SRP, 2014)	From data	Ecuador b	x				Centr Am.	Latin Am.
Ecuador	1986	(ESPOL, CEPLAES, & ILDIS, 1987)	From data	Ecuador b	x			Yes	Centr Am.	Latin Am.
Ecuador	NA	(Santos & Villon, 1998)	NA					Yes	Centr Am.	Latin Am.
Egypt	2012-2014	(GAFRD, n.d.)	From data: not mechanised	Egypt a	x	x	x		Middle East	Arab World
Egypt	1950-1960	(FAO, n.d.-d)	From data: not mechanised	Egypt a		x	x		Middle East	Arab World
Egypt	1996-2009	(FAO, n.d.-c)	From data: not mechanised	Egypt a	x	x	x	Yes	Middle East	Arab World
Egypt		(FAO, 2010b)	NA					Yes	Middle East	Arab World
El Salvador	2010	(OSPESCA, 2012)	< 10 m		x		x		Centr Am.	Latin Am.

Equatorial Guinea	1984	(Weber & Durand, 1986)	From data: canoes			x			Sub Saharan	Sub Saharan	
Equatorial Guinea	1965 1974	(Everett, 1976)	From data: canoes		x	x	x		Sub Saharan	Sub Saharan	
Equatorial Guinea	2013	(FAO, 2015b)	From data: canoes		x		x		Sub Saharan	Sub Saharan	
Equatorial Guinea	1985-2015	Estimate	-	Eq. Guinea a		x			Sub Saharan	Sub Saharan	
Eritrea	1950	Estimate	From data: no industrial, all foreign	Eritrea a	x				Sub Saharan	Sub Saharan	
Eritrea	1962 1966 1970	(FAO, 1993)	From data: no industrial, all foreign		x		x	Yes	Sub Saharan	Sub Saharan	
Eritrea	2009	(FAO, 2014a)	From data: no industrial, all foreign	Eritrea b	x		x		Sub Saharan	Sub Saharan	
Estonia	1950-2015	(European Commission, n.d.)	< 12m and without towed gears.		x	x		Yes	Europe	Europe	
Faroe Islands	1994-2003	(Løkkegaard, Andersen, Boje, Frost, & Hovgård, 2007)	From data: Costal & < 15 GT		x	x		Yes	Europe	Europe	dep Denmark
Fiji, Republic of	1991	(McCoy, 1991)	From data: all not tuna/shark		x		x		Pacif. Isl.	Oceania	
Fiji, Republic of	1976-1994	(Sharma, 1995)	From data: all not tuna/shark	Fiji a		x			Pacif. Isl.	Oceania	
Fiji, Republic of	1989-2015	(WCPFC, 2016b)	From data: all not tuna/shark	Fiji a		x			Pacif. Isl.	Oceania	
Fiji, Republic of		(WCPFC, n.d.-d)	From data: all not tuna/shark					Yes	Pacif. Isl.	Oceania	

Appendix 3 - Extended data sources and definitions used in Chapter 4 (Cont.)

Finland	1950-2015	(European Commission, n.d.)	< 12m and without towed gears.		x	x		Yes	Europe	Europe
France	1950-2015	(European Commission, n.d.)	< 12m and without towed gears.		x	x		Yes	Europe	Europe
Gabon	1965 1974 1976	(Everett, 1976)	From data: pirogues		x	x			Sub Saharan	Sub Saharan
Gabon	1995	(Kébé, Njock, & Gallène, 1996)	From data: pirogues	Gabon a		x		Yes	Sub Saharan	Sub Saharan
Gabon	2006	(FAO, 2007a)	From data: pirogues		x	x		Yes	Sub Saharan	Sub Saharan
Gambia	1983-1992	(Akinyemi & Everett, 1993)	From data: canoes		x	x	x		NW Africa	Sub Saharan
Gambia	1993	(Horemans, Ajayi, & Gallène, 1996)	From data: canoes			x		Yes	NW Africa	Sub Saharan
Gambia	2006	(UNCTAD, 2014)	From data: canoes		x				NW Africa	Sub Saharan
Georgia	1956-1993	(Beaudry & Folsom, 1993)	From data			x			Europe	Europe
Georgia	1987 1991	(FAO, 2005a)	From data		x	x		Yes	Europe	Europe
Georgia	1950 1970	Estimate	NA	Georgia a	x				Europe	Europe
Georgia	2007 (I) 2005 (A)	(Castilla-Espino, García-del-Hoyo, Metreveli, & Bilashvili, 2014)	From data	Georgia b	x	x		Yes	Europe	Europe

Appendix 3 - Extended data sources and definitions used in Chapter 4 (Cont.)

Georgia	1995-2004	(Castilla-Espino et al., 2014; D. Sanders, 2014)	NA	Georgia c		x			Europe	Europe	
Germany	1950-2015	(European Commission, n.d.)	< 12m and without towed gears.		x	x		Yes	Europe	Europe	
Ghana	1958	(FAO, n.d.-d)	From data: pirogues/canoes	Ghana a	x		x		Sub Saharan	Sub Saharan	
Ghana	2003	(FAO, n.d.-c)	From data: pirogues/canoes	Ghana a			x	Yes	Sub Saharan	Sub Saharan	
Ghana	1990 1992	(Wayo Seini, 1995)	From data: pirogues/canoes		x		x		Sub Saharan	Sub Saharan	
Ghana	1954-1974	(Kwadjosse, 2009a, 2009b)	NA		x	x			Sub Saharan	Sub Saharan	
Ghana	1980-2010	(Sackey-Mensah, 2012)	From data: pirogues/canoes		x	x	x		Sub Saharan	Sub Saharan	
Greece	1950-2015	(European Commission, n.d.)	< 12m and without towed gears.		x	x		Yes	Europe	Europe	
Greenland	1950-1967	(FAO, n.d.-d)	inshore, < 120 GT	Greenland a	x		x		Europe	Europe	dep Denmark
Greenland	1995-2014	(FAO, 2011b, 2013, 2015c)	inshore, < 120 GT	Greenland a	x				Europe	Europe	dep Denmark
Greenland	2012	(Berthelsen, 2014)	inshore, < 120 GT		x	x			Europe	Europe	dep Denmark
Greenland	1950	Estimate	NA	Greenland b		x			Europe	Europe	dep Denmark
Greenland	1996	(ICES, 2004)	inshore, < 120 GT			x	x		Europe	Europe	dep Denmark
Greenland	2004-2007	(SG, 2010)	inshore, < 120 GT	Greenland a	x	x			Europe	Europe	dep Denmark

Appendix 3 - Extended data sources and definitions used in Chapter 4 (Cont.)

Grenada	1946 1972 1980	(Pool, 1995)	From data	Grenada a	x				Caribbeans	Latin Am.
Grenada	1958-1967	(FAO, n.d.-d)	From data	Grenada a	x		x		Caribbeans	Latin Am.
Grenada	2006-2011	(FAO, n.d.-c)	From data	Grenada a	x	x	x	Yes	Caribbeans	Latin Am.
Grenada	1987 2007	(JICA, 2009)	From data	Grenada a	x	x			Caribbeans	Latin Am.
Grenada	1995	(Chakalall & Cochrane, 2004)	From data	Grenada a		x			Caribbeans	Latin Am.
Grenada	2007-2010	(Masters, 2012, 2014)	From data	Grenada a	x	x			Caribbeans	Latin Am.
Guatemala	1999 2004	(FAO, 2005c)	From data: outboard vessels	Guatemala a	x	x			Centr Am.	Latin Am.
Guatemala	2010	(OSPESCA, 2012)	From data: outboard vessels	Guatemala a	x	x			Centr Am.	Latin Am.
Guatemala	1999	(PRADEPESCA, 1999)	From data: outboard vessels	Guatemala a	x		x		Centr Am.	Latin Am.
Guatemala	1958-1967	(FAO, n.d.-d)	From data: outboard vessels	Guatemala a	x	x	x		Centr Am.	Latin Am.
Guinea	1961-1996	(Domain, Chavance, & Diallo, 1999)	From data. Industrial is "advanced artisanal"	Guinea a	x	x		Yes	NW Africa	Sub Saharan
Guinea	1998	(Dia, 2000)	From data		x				NW Africa	Sub Saharan
Guinea	2001	(FAO, 2005d)	From data		x		x		NW Africa	Sub Saharan
Guinea	2007 2010	(COMHAFAT, 2012b)	From data		x		x		NW Africa	Sub Saharan

Appendix 3 - Extended data sources and definitions used in Chapter 4 (Cont.)

Guinea	2017	(FAO, n.d.-a)	NA			x			NW Africa	Sub Saharan
Guinea	2017	(SRFC, 2016)	From data		x				NW Africa	Sub Saharan
Guinea-Bissau	1974	(Everett, 1976)	From data: Canoes with < 60 hp		x	x			NW Africa	Sub Saharan
Guinea-Bissau	1984	(Weber & Durand, 1986)	From data: Canoes with < 60 hp			x			NW Africa	Sub Saharan
Guinea-Bissau	1980	(Lawson & Robinson, 1983)	From data: Canoes with < 60 hp		x		x		NW Africa	Sub Saharan
Guyana	1986-1996	(Shepherd, Hackett, & Charles, 1999)	From data: dugout canoes	Guyana a		x		Yes	S America	Latin Am.
Guyana	2007	(Maison, 2007)	From data: dugout canoes	Guyana a	x	x			S America	Latin Am.
Guyana	2015	(FD Guyana, 2016)	From data: dugout canoes	Guyana a		x			S America	Latin Am.
Guyana		(Project GloBAL, 2008)	From data: dugout canoes					Yes	S America	Latin Am.
Haiti	1999	(CRFM, 2003)	From data: no industrial		x		x		Caribbeans	Latin Am.
Haiti	2008	(MARNDR, 2010)	From data: no industrial		x		x		Caribbeans	Latin Am.
Haiti	2009	(JICA, 2011)	From data: no industrial		x		x	Yes	Caribbeans	Latin Am.
Honduras	1958	(FAO, n.d.-d)	NA	Honduras a		x			Centr Am.	Latin Am.
Honduras	2005-2010	(FAO, n.d.-c)	NA	Honduras a		x		Yes	Centr Am.	Latin Am.
Honduras	1950	Estimate	NA	Honduras b	x				Centr Am.	Latin Am.
Honduras	1974-1988	(USAID & SECPLAN, 1989)	NA	Honduras c		x			Centr Am.	Latin Am.

Appendix 3 - Extended data sources and definitions used in Chapter 4 (Cont.)

Honduras	1990	(Pratt & Quijandría, 1997)	NA	Honduras c		x			Centr Am.	Latin Am.
Honduras	1995	(DIGEPESCA, 2003)	From data		x				Centr Am.	Latin Am.
Honduras	2010	(OSPESCA, 2012)	From data		x		x		Centr Am.	Latin Am.
Honduras	2009-2013	(DIGEPESCA, n.d.)	NA	Honduras c		x			Centr Am.	Latin Am.
Iceland	1995 1998	(FAO, n.d.-b)	< 25GT	Iceland a	x	x	x		Europe	Europe
Iceland	1950-1967	(FAO, n.d.-d)	< 25 GT	Iceland a	x	x	x		Europe	Europe
Iceland	1999-2015	(Statice, n.d.)	From data: < 25 GT	Iceland a	x	x		Yes	Europe	Europe
India	1950	(Ministry of Agriculture, 1951)	non mechanised crafts			x	x		Indian Pen.	Indian Pen. / Asia
India	1977	(CMFRI, 1978)	non mechanised crafts	India a	x	x	x		Indian Pen.	Indian Pen. / Asia
India	1969	(MoA, 1976)	non mechanised crafts	India b		x			Indian Pen.	Indian Pen. / Asia
India	1980	(CMFRI, 1981)	non mechanised crafts	India a	x	x			Indian Pen.	Indian Pen. / Asia
India	1985 1995	(Immanuel, Pillai, Vivekandan, Kurup, & Srinath, 2003)	non mechanised crafts	India a	x	x	x		Indian Pen.	Indian Pen. / Asia
India	1993*	(Heitzman & Worden, 1996)	non mechanised crafts	India c					Indian Pen.	Indian Pen. / Asia
India	1998	(Vivekanandan, Srinath, Pillai,	non mechanised crafts		x				Indian Pen.	Indian Pen. / Asia

Appendix 3 - Extended data sources and definitions used in Chapter 4 (Cont.)

		Immanuel, & Kurup, 2003)								
India	2000	(Infantina, Jayaraman, Umamaheswari, Viswanatha, & Ranjith, 2016)	non mechanised crafts	India d	x	x			Indian Pen.	Indian Pen. / Asia
India	2005	(CMFRI, 2005)	non mechanised crafts	India a	x	x	x		Indian Pen.	Indian Pen. / Asia
India	2010	(CMFRI, 2010)	non mechanised crafts		x	x	x		Indian Pen.	Indian Pen. / Asia
India	NA	(Zacharia, n.d.)	NA	India e				Yes	Indian Pen.	Indian Pen. / Asia
Indonesia	1957-1967	(FAO, n.d.-d)	<5 GT (incl outboard)	Indonesia a	x	x	x		SE Asia	SE Asia/ Asia
Indonesia	1975-2014	(SEAFDEC, n.d.)	<5 GT (incl outboard)	SEAFDEC (1)	x	x	x		SE Asia	SE Asia/ Asia
Indonesia	NA	(WCPFC, n.d.-d)	NA					Yes	SE Asia	SE Asia/ Asia
Iran (Islamic Rep. of)	1974	(World Bank, 1974)	< 100 GT		x	x			Middle East	Arab World
Iran (Islamic Rep. of)	1995-2014	(FAO, 2011b, 2013, 2015c)	< 100 GT	Iran a	x		x		Middle East	Arab World
Iran (Islamic Rep. of)	2009-2013	(Nergi, 2014)	< 100 GT	Iran a	x	x			Middle East	Arab World
Iran (Islamic Rep. of)	2012-2016	(Kakoolaki, 2017)	< 100 GT	Iran a		x			Middle East	Arab World
Iran (Islamic Rep. of)	2003-2010	(FAO, n.d.-c)	< 100 GT	Iran a	x	x		Yes	Middle East	Arab World

Appendix 3 - Extended data sources and definitions used in Chapter 4 (Cont.)

Iran (Islamic Rep. of)	2002-2012	(FAO, n.d.-b)	< 100 GT	Iran a	x	x			Middle East	Arab World
Iraq	1950	Estimate	NA	Iraq a					Middle East	Arab World
Iraq	1994 2001 2011	(A.-R. M. Mohamed & Qasim, 2014)	< 75 HP		x	x			Middle East	Arab World
Ireland	1950-2015	(European Commission, n.d.)	< 12m and without towed gears.		x	x		Yes	Europe	Europe
Israel	1955	(Cohen, 1957)	From data: all but trawls/ pelagics	Israel a		x			Middle East	Arab World
Israel	1990	(Edelist, 2013)	From data: all but trawls/ pelagics	Israel a		x			Middle East	Arab World
Israel	2005	(FAO, 2007b)	From data: all but trawls/ pelagics	Israel a	x	x			Middle East	Arab World
Israel	2007 2009 2010	(Levy et al., 2015)	From data: all but trawls/ pelagics	Israel a	x	x			Middle East	Arab World
Israel		(Golani, Edelist, Lerner, Sonin, & Motro, 2017)	From data: all but trawls/ pelagics					Yes	Middle East	Arab World
Italy	1950-2015	(European Commission, n.d.)	< 12m and without towed gears.		x	x		Yes	Europe	Europe
Jamaica	1962	(H. Gordon, 1964)	From data: inshore fisheries		x				Caribbeans	Latin Am.
Jamaica	1997	(CFRAMP, 2000)	From data: inshore fisheries		x	x	x		Caribbeans	Latin Am.
Jamaica	1997 2002	(FAO, 2005b)	From data: inshore fisheries		x	x		Yes	Caribbeans	Latin Am.

Appendix 3 - Extended data sources and definitions used in Chapter 4 (Cont.)

Japan	1950-2003	(Statistics Japan, 2012)	< 10GT		x	x	x	Yes	NE Asia	NE Asia/Asia	
Japan	2004-2014	(Statistics Japan, n.d.)	< 10GT		x	x	x	Yes	NE Asia	NE Asia/Asia	
Jordan	1979	(Barrania, 1979)	From data: no Industrial		x			Yes	Middle East	Arab World	
Jordan	1995	(PERSGA, 2001)	From data: no Industrial		x				Middle East	Arab World	
Kazakhstan	-	-	-	-	-	-	-	-	-	-	Caspian Sea only
Kenya	1979	(Odidi Okidi, 1979)	From data	Kenya a	x		x		Sub Saharan	Sub Saharan	
Kiribati	1991	(McCoy, 1991)	From data: skiffs/ opposed to tuna		x		x	Yes	Pacif. Isl.	Oceania	
Kiribati	2002-2003	(Awira, 2004)	From data: skiffs/ opposed to tuna		x			Yes	Pacif. Isl.	Oceania	
Kiribati	1988	(SPC, 1988)	From data: skiffs/ opposed to tuna		x			Yes	Pacif. Isl.	Oceania	
Kiribati	2007-2012	(WCPFC, 2013)	From data: skiffs/ opposed to tuna	Kiribati a	x	x		Yes	Pacif. Isl.	Oceania	
Kiribati	2016	(WCPFC, n.d.-d)	NA			x		Yes	Pacif. Isl.	Oceania	
Korea, Dem. People's Rep. of	-	-	-	-	-	-	-	-	-	-	Not considered.
Korea, Rep. of	1952-1953	(Kosis, n.d.-b)	< 10GT		x	x	x		NE Asia	NE Asia/Asia	
Korea, Rep. of	1992-2015	(Kosis, n.d.-a)	< 10GT		x	x	x	Yes	NE Asia	NE Asia/Asia	
Korea, Rep. of	1954-1972	(Folsom, 1976)	< 10GT	Korea a	x	x	x		NE Asia	NE Asia/Asia	

Appendix 3 - Extended data sources and definitions used in Chapter 4 (Cont.)

Korea, Rep. of	1985	("South Korea," 1990)	< 10GT	Korea a	x	x			NE Asia	NE Asia/Asia
Kuwait	NA	-	Decision: traditional vessels, all but trawls	-					Middle East	Arab World
Latvia	1950-2015	(European Commission, n.d.)	< 12m and without towed gears.		x	x		Yes	Europe	Europe
Lebanon	NA	-	Decision: All but trawls, seine and longlines	-					Middle East	Arab World
Liberia	1984	(Weber & Durand, 1986)	<40 hp / < 60 feet			x			Sub Saharan	Sub Saharan
Liberia	1965 1974	(Everett, 1976)	<40 hp / < 60 feet			x			Sub Saharan	Sub Saharan
Libya	1972	(CIA, 1974)	From data: traditional crafts			x			Maghreb	Arab World
Libya	1984	(Weber & Durand, 1986)	From data: traditional crafts		x	x	x		Maghreb	Arab World
Libya	1993	(Lamboeuf et al., 2000)	From data: traditional crafts		x				Maghreb	Arab World
Libya	2000	(NEPAD & CAADP, 2006)	From data: traditional crafts		x	x	x		Maghreb	Arab World
Lithuania	1950-2015	(European Commission, n.d.)	< 12m and without towed gears.		x	x		Yes	Europe	Europe
Madagascar	1964-1967	(FAO, n.d.-d)	From data	Madagascar a	x	x			Sub Saharan	Sub Saharan
Madagascar	1984	(Weber & Durand, 1986)	From data	Madagascar a		x			Sub Saharan	Sub Saharan
Madagascar	2010-2015	(WIOFish, n.d.)	From data	Madagascar b	x	x			Sub Saharan	Sub Saharan

Appendix 3 - Extended data sources and definitions used in Chapter 4 (Cont.)

Malaysia	1950-2015	(DoF Malaysia, n.d.)	outboard & < 40HP	Malaysia a	x	x	x	Yes	SE Asia	SE Asia/Asia	
Maldives	1972 1982	(Sathiendrakumar & Tisdell, 1986)	From data: all not tuna		x				Indian Pen.	Indian Pen. / Asia	
Maldives	1995-1997 2002-2009	(MOFARM, n.d.)	From data: all not tuna		x				Indian Pen.	Indian Pen. / Asia	
Maldives	1997-2002	(Anderson, Adam, & Rasheed, 2003)	From data: all not tuna			x			Indian Pen.	Indian Pen. / Asia	
Maldives	2014-2015	(Ahusan et al., 2016)	From data: all not tuna			x			Indian Pen.	Indian Pen. / Asia	
Maldives	NA	(S. Mohamed, 2007)	NA					Yes	Indian Pen.	Indian Pen. / Asia	
Malta	1950-2015	(European Commission, n.d.)	< 12m and without towed gears.		x	x		Yes	Europe	Europe	
Marshall Islands	1950	Estimate	Pirogues, non tuna	Marshall Isl. a	x				Pacif. Isl.	Oceania	Free assoc. with USA
Marshall Islands	1991	(McCoy, 1991)	Pirogues, non tuna		x		x		Pacif. Isl.	Oceania	Free assoc. with USA
Marshall Islands	1991-2015	Estimate	Pirogues, non tuna	Marshall Isl. b	x				Pacif. Isl.	Oceania	Free assoc. with USA
Marshall Islands	2000-2004	(Joseph, 2005)	Pirogues, non tuna			x			Pacif. Isl.	Oceania	Free assoc. with USA
Marshall Islands	2001-2005	(Muller, 2006)	Pirogues, non tuna			x			Pacif. Isl.	Oceania	Free assoc. with USA
Marshall Islands	2007-2011	(WCPFC, 2016a)	Pirogues, non tuna			x			Pacif. Isl.	Oceania	Free assoc. with USA

Appendix 3 - Extended data sources and definitions used in Chapter 4 (Cont.)

Marshall Islands	2017	(WCPFC, n.d.-d)	Pirogues, non tuna			x			Pacif. Isl.	Oceania	Free assoc. with USA
Mauritania	1986 2007	(Iborra Martín, 2010)	From data		x	x			Maghreb	Arab World	
Mauritania	2010-2015	(ONS, 2017)	From data			x			Maghreb	Arab World	
Mauritania	2002	(SRFC, 2016)	From data			x			Maghreb	Arab World	
Mauritania	2016	(MPEM-DGERH, 2016)	From data		x				Maghreb	Arab World	
Mauritania	2009	(Diarra, 2013)	From data		x	x			Maghreb	Arab World	
Mauritania		(IMROP, 2013)	From data					Yes	Maghreb	Arab World	
Mauritius	1984	(Weber & Durand, 1986)	From data: OB, no trawl/seine		x		x		Sub Saharan	Sub Saharan	
Mauritius	1997	(FAO, 2000b)	From data: OB, no trawl/seine		x	x			Sub Saharan	Sub Saharan	
Mauritius	2006	(Bolaky, 2006)	From data: OB, no trawl/seine		x	x		Yes	Sub Saharan	Sub Saharan	
Mexico	2007-2010	(FAO, n.d.-c)	NA. comparison	Mexico a			x	Yes	Centr Am.	Latin Am.	
Mexico	1950-1958 1962-1967	(FAO, n.d.-d)	NA comparison	Mexico a			x		Centr Am.	Latin Am.	
Mexico	1950-2015	(CONAPESCA, n.d.; DoF Mexico, n.d.; SEMARNAP, n.d.)	From data: < 10 Net Tons / "Ribeñera"	Mexico a	x	x	x		Centr Am.	Latin Am.	
Micronesia, Fed.States of	1950	Estimate	Outboard pirogues	FSM a	x	x			Pacif. Isl.	Oceania	Free assoc. with USA
Micronesia, Fed.States of	1991	(McCoy, 1991)	Outboard pirogues		x		x	Yes	Pacif. Isl.	Oceania	Free assoc. with USA

Appendix 3 - Extended data sources and definitions used in Chapter 4 (Cont.)

Micronesia, Fed.States of	1992-2015	Estimate	Outboard pirogues		x				Pacif. Isl.	Oceania	Free assoc. with USA
Micronesia, Fed.States of	2004 2007	(FAO, 2010d)	Outboard pirogues			x			Pacif. Isl.	Oceania	Free assoc. with USA
Micronesia, Fed.States of	2017	(WCPFC, n.d.-d)	Outboard pirogues			x			Pacif. Isl.	Oceania	Free assoc. with USA
Monaco	-	-	-	-	-	-	-	-	-	-	Not considered.
Montenegro	2002	(FAO, 2004a)	From data: excluding trawl and purse seine	Montenegro a	x	x		Yes	Europe	Europe	
Montenegro	2004	(Accadia & Franquesa, 2006)	From data: excluding trawl and purse seine		x	x			Europe	Europe	
Montenegro	2001-2012	(Djurović & Marković, 2013)	From data: excluding trawl and purse seine		x	x			Europe	Europe	
Morocco	1950-1951	(FAO, n.d.-d)	From data	Morocco a		x	x		Maghreb	Arab World	
Morocco	1950-1973	(Poinsard & Villegas, 1975)	From data	Morocco a		x			Maghreb	Arab World	
Morocco	1950-1997	(Baddyr & Guénette, 1997)	From data	Morocco a	x	x		Yes	Maghreb	Arab World	
Morocco		(Fahfouhi & Roullot, 1984)	From data	Morocco a				Yes	Maghreb	Arab World	
Morocco	1975-1985	(El Gharbi & Idelhaj, 1988)	From data	Morocco a		x			Maghreb	Arab World	
Morocco	1993	(Lamine, 1995)	From data	Morocco a					Maghreb	Arab World	
Morocco	1992	(El Ouairi & Idelhaj, 1993)	From data	Morocco a	x	x			Maghreb	Arab World	

Appendix 3 - Extended data sources and definitions used in Chapter 4 (Cont.)

Morocco		(Cunningham & Lamine, 1992)	From data	Morocco a	x			Yes	Maghreb	Arab World
Morocco	2009-2015	(MPM, n.d.)	From data	Morocco a	x	x		Yes	Maghreb	Arab World
Morocco	1995 2000 2003-2007 2010	(FAO, 2011b, 2013, 2015c)	From data				x		Maghreb	Arab World
Mozambique	1950-1967	(FAO, n.d.-d)	From data	Mozambique a	x	x	x		Sub Saharan	Sub Saharan
Mozambique	2004 2007 2012	(MdP, 2013)	From data		x				Sub Saharan	Sub Saharan
Mozambique	2009-2012	(MdP, 2014)	From data			x			Sub Saharan	Sub Saharan
Mozambique	2012-2015	(MMAIP, 2016)	From data		x	x			Sub Saharan	Sub Saharan
Myanmar	1991 1996 2004-2010	(CSO, 2012)	From data: inshore	Myanmar a		x			SE Asia	SE Asia/Asia
Myanmar	2010-2014	(ILO, 2015)	From data: inshore	Myanmar a	x	x	x		SE Asia	SE Asia/Asia
Myanmar	1982	(Sivasubramaniam, 1985)	From data: inshore	Myanmar a	x	x	x		SE Asia	SE Asia/Asia
Myanmar	1997-2000	(Myint Pe, 2004)	From data: inshore	Myanmar a	x		x		SE Asia	SE Asia/Asia
Myanmar	1978	(Raja, 1980)	From data: inshore	Myanmar a	x		x		SE Asia	SE Asia/Asia
Myanmar	1997-2007	(Khin Maung Soe, 2008)	From data: inshore	Myanmar a	x	x	x		SE Asia	SE Asia/Asia
Myanmar	1999-2005 2008-2010	(FAO, n.d.-c)	From data: inshore/undecked	contradict. data.	x	x		Yes	SE Asia	SE Asia/Asia

Appendix 3 - Extended data sources and definitions used in Chapter 4 (Cont.)

Myanmar	1999 2002-2005 2008-2013	(SEAFDEC, n.d.)	From data: inshore	SEAFDEC (4)	x	x	x	Yes	SE Asia	SE Asia/Asia
Namibia	1950-2015	(Batty et al., 2005)	Officially, no artisanal in Namibia	Namibia a					Sub Saharan	Sub Saharan
Namibia	2006-2010	(COMHAFAT, 2012a)	Officially, no artisanal in Namibia						Sub Saharan	Sub Saharan
Nauru	1991	(McCoy, 1991)	From data: no industrial except 2 longliners		x		x	Yes	Pacif. Isl.	Pacif. Isl.
Nauru	1992	(Welch, 2015)	From data: no industrial except 2 longliners		x				Pacif. Isl.	Pacif. Isl.
Nauru	2016	(WCPFC, 2017a)	From data: no industrial except 2 longliners		x		x		Pacif. Isl.	Pacif. Isl.
Netherlands	1950-2015	(European Commission, n.d.)	< 12m and without towed gears.		x	x		Yes	Europe	Europe
New Zealand	1950 1955 1960 1965 1969	(Vooren, 1974)	< 15m / non motorised trawls	New Zealand a		x		Yes	Australia NZ	Oceania
New Zealand	1984 1987 1992 1995	(van Hoof, 2010)	< 15m / non motorised trawls	New Zealand a					Australia NZ	Oceania
New Zealand	1950-1958	(FAO, n.d.-d)	< 15m / non motorised trawls	New Zealand a	x	x			Australia NZ	Oceania
New Zealand	1995-2012	(FAO, n.d.-b)	< 15m / non motorised trawls	New Zealand a	x	x			Australia NZ	Oceania
New Zealand	2002-2010	(FAO, n.d.-c)	< 15m / non motorised trawls	New Zealand a	x	x		Yes	Australia NZ	Oceania

Appendix 3 - Extended data sources and definitions used in Chapter 4 (Cont.)

Nicaragua	1976	(Urroz Escobar, 1978)	From data			x			Centr Am.	Latin Am.	
Nicaragua	2010	(OSPESCA, 2012)	From data		x		x		Centr Am.	Latin Am.	
Nigeria	1971-1994	(Ssentongo, Ukpe, & Ajayi, 1986)	From data: canoes	Nigeria a	x	x	x		Sub Saharan	Sub Saharan	
Nigeria	1990-1997	(FAO, 2010a)	From data: canoes	Nigeria a	x	x	x		Sub Saharan	Sub Saharan	
Niue	1991	(McCoy, 1991)	From data: no industrial		x		x		Pacif. Isl.	Pacif. Isl.	
Niue	2003	(Pasisi, 2003)	From data: no industrial		x		x		Pacif. Isl.	Pacif. Isl.	
Niue	2006	(FAO, 2010e)	From data: no industrial		x		x		Pacif. Isl.	Pacif. Isl.	
Norway	1950-2015	(Statistics Norway, n.d.)	Decision (EU): <12m		x	x			Europe	Europe	
Norway	var. years	(Fiskeridirektoratet, n.d.)	NA	Norway a				Yes	Europe	Europe	
Oman	1985-1987	(Maynard, 1988)	From data		x	x	x		Middle East	Arab World	
Oman	2012-2016	(MAF, n.d.)	traditional, undecked or < 10 GRT	Oman a	x	x			Middle East	Arab World	
Pakistan	2003-2011	(PBS, 2012)	all non trawl		x	x	x		Indian Pen.	Indian Pen. / Asia	
Palau	1991	(McCoy, 1991)	From data: no industrial	Palau a	x		x	Yes	Pacif. Isl.	Pacif. Isl.	Free assoc. with USA
Palau	1950-2015	Estimate	From data: no industrial	Palau b	x				Pacif. Isl.	Pacif. Isl.	Free assoc. with USA
Palestine	-	-	-	-	-	-	-	-	Middle East	Arab World	Part. landlocked, combined w. Israel

Appendix 3 - Extended data sources and definitions used in Chapter 4 (Cont.)

Panama	2005-2010	(FAO, n.d.-c)	NA. comparison	Panama a	x	x	x	Yes	Centr Am.	Latin Am.
Panama	1995-2012	(FAO, n.d.-b)	NA. comparison	Panama a	x	x	x		Centr Am.	Latin Am.
Panama	2002-2016	(ARAP, 2017)	From data			x			Centr Am.	Latin Am.
Panama	2010	(OSPESCA, 2012)	From data		x		x		Centr Am.	Latin Am.
Panama	2013-2015	(ARAP, 2014, 2015)	From data		x				Centr Am.	Latin Am.
Papua New Guinea	1950	Estimate	all not tuna/ shark	PNG a	x				Pacif. Isl.	Oceania
Papua New Guinea	1952	(SPC, 1962)	all not tuna/ shark			x			Pacif. Isl.	Oceania
Papua New Guinea	1989-1991	(McCoy, 1991)	all not tuna/ shark	PNG b	x		x		Pacif. Isl.	Oceania
Papua New Guinea	1976 1981	(FAO, 2010f)	all not tuna/ shark			x			Pacif. Isl.	Oceania
Papua New Guinea	1985-1986	(SPC, 1987)	all not tuna/ shark			x			Pacif. Isl.	Oceania
Papua New Guinea	1992-2004	(Kumoru & Koren, 2006)	all not tuna/ shark	PNG c		x			Pacif. Isl.	Oceania
Papua New Guinea	1997-2002	(Kumoru, 2002)	all not tuna/ shark	PNG c		x			Pacif. Isl.	Oceania
Papua New Guinea	2005-2015	(WCPFC, n.d.-b)	all not tuna/ shark	PNG c		x			Pacif. Isl.	Oceania
Papua New Guinea	2015	Estimate	all not tuna/ shark	PNG d	x				Pacif. Isl.	Oceania
Peru	1953-1962	(IREMAR, 1963)	From data	Peru a		x			S America	Latin Am.

Appendix 3 - Extended data sources and definitions used in Chapter 4 (Cont.)

Peru	1969	(IMARPE, 1970)	From data	Peru a		x			S America	Latin Am.
Peru	1964-1969	(IMARPE, 1969)	From data	Peru a		x			S America	Latin Am.
Peru	1971	(IMARPE, 1972)	From data	Peru a		x			S America	Latin Am.
Peru	1960-1972	(IMARPE, 1973)	From data	Peru a		x			S America	Latin Am.
Peru	1970-1980 1982	(Berrios, 1983)	From data	Peru a	x		x		S America	Latin Am.
Peru	1990-1995	(INEI, 1997)	From data		x	x			S America	Latin Am.
Peru	1991-1996	(INEI, 1998)	From data		x	x			S America	Latin Am.
Peru	1995	(IMARPE, 1997)	From data		x			Yes	S America	Latin Am.
Peru	2001-2007	(INEI, n.d.)	From data			x			S America	Latin Am.
Peru	1950-2006	(Aranda, 2009)	From data	Peru a		x			S America	Latin Am.
Peru	2005	(PRODUCE, 2010)	From data		x		x		S America	Latin Am.
Peru	2010-2011	(PRODUCE, n.d.-b)	From data			x			S America	Latin Am.
Peru	2012-2015	(PRODUCE, n.d.-c)	From data	Peru b	x	x	x		S America	Latin Am.
Peru	NA	(PRODUCE, n.d.-a)	NA	Peru c				Yes	S America	Latin Am.
Philippines	1950-1966	(FAO, n.d.-d)	< 20 GT (incl municipal & 3-20GT)	Philippines a		x			SE Asia	SE Asia/ Asia
Philippines	1948 1971 1977	(Dalzell, Corpuz, Ganaden, & Pauly, 1987)	< 20 GT (incl municipal & 3-20GT)	Philippines a	x		x		SE Asia	SE Asia/ Asia
Philippines	1980	(NSO, 1981)	< 20 GT (incl municipal & 3-20GT)	Philippines a	x		x		SE Asia	SE Asia/ Asia

Appendix 3 - Extended data sources and definitions used in Chapter 4 (Cont.)

Philippines	1985	(BFAR, n.d.-b)	< 20 GT (incl municipal & 3-20GT)	Philippines a	x		x	SE Asia	SE Asia/ Asia
Philippines	1976	(I. Smith, Puzon, & Vidal-Libuano, 1980)	< 20 GT (incl municipal & 3-20GT)	Philippines a	x		x	SE Asia	SE Asia/ Asia
Philippines	1969	(FAO, 1971)	< 20 GT (incl municipal & 3-20GT)	Philippines a	x		x	SE Asia	SE Asia/ Asia
Philippines	2000	(BFAR, 2001)	< 20 GT (incl municipal & 3-20GT)	used only as err.				SE Asia	SE Asia/ Asia
Philippines	2002	(NSO, 2005)	< 20 GT (incl municipal & 3-20GT)	Philippines a	x	x	x	SE Asia	SE Asia/ Asia
Philippines	1967-1987*	(Barut, Santos, & Garces, 1997)	< 20 GT (incl municipal & 3-20GT)	Philippines a		x		SE Asia	SE Asia/ Asia
Philippines	1976-1988	(SEAFDEC, n.d.)	< 20 GT (incl municipal & 3-20GT)	SEAFDEC (2) Philippines a		x		SE Asia	SE Asia/ Asia
Philippines	1977-1978 1980-1985 1987-1989 1992 1994 1997-1999 2007	(BFAR, n.d.-a)	< 20 GT (incl municipal & 3-20GT)	Philippines a		x		SE Asia	SE Asia/ Asia
Philippines	2011-2014	(PSA, 2015)	< 20 GT (incl municipal & 3-20GT)	Philippines a		x		SE Asia	SE Asia/ Asia
Philippines	2016	(Maritime Industry Authority, 2016)	< 20 GT (incl municipal & 3-20GT)			x		SE Asia	SE Asia/ Asia

Appendix 3 - Extended data sources and definitions used in Chapter 4 (Cont.)

Poland	1950-2015	(European Commission, n.d.)	< 12m and without towed gears.		x	x	Yes	Europe	Europe
Portugal	1950-2015	(European Commission, n.d.)	< 12m and without towed gears.		x	x	Yes	Europe	Europe
Qatar	1980 1992	(Al-Ansi & Priede, 1996)	From data: few industrial (closed in 1993)		x			Middle East	Arab World
Qatar	1998-2015	(De Young, 2006)	From data: few industrial (closed in 1993)	Qatar a	x			Middle East	Arab World
Qatar	1980-1992	(Al-Ansi & Priede, 1996)	From data: few industrial (closed in 1993)			x	Yes	Middle East	Arab World
Romania	1950-2015	(European Commission, n.d.)	< 12m and without towed gears.		x	x	Yes	Europe	Europe
Russian Federation	1969-1972	(Sealy, 1974)	From data: < 100 GRT/ 55kW	Russia a		x		Europe	Europe
Russian Federation	1974	(CIA, 1975)	From data: < 100 GRT/ 55kW	Russia a		x		Europe	Europe
Russian Federation	1980-1987	(Crone Bilger, 1990)	From data: < 100 GRT/ 55kW	Russia a		x		Europe	Europe
Russian Federation	1993	(Beaudry & Folsom, 1993)	From data: < 100 GRT/ 55kW	Russia b		x		Europe	Europe
Russian Federation	1995-2014	(VNIRO, 2015)	From data: < 100 GRT/ 55kW	Russia c		x		Europe	Europe
Russian Federation	2005	(FAO, 2008d)	From data: < 100 GRT/ 55kW		x			Europe	Europe
Russian Federation	1961 1966-1971	(Yanyshev-Nesterova, 2014)	From data: < 100 GRT/ 55kW	Russia d	x			Europe	Europe

Appendix 3 - Extended data sources and definitions used in Chapter 4 (Cont.)

Russian Federation	1990 1994 1998	(Ivanova, 2005)	From data: < 100 GRT/ 55kW	Russia d	x				Europe	Europe
Russian Federation	1953-1956	(FAO, n.d.-d)	From data: < 100 GRT/ 55kW	Russia d	x		x		Europe	Europe
Russian Federation	NA	(FAO, n.d.-c)	From data: < 100 GRT/ 55kW	Russia e				Yes	Europe	Europe
Saint Kitts & Nevis	2013	(DMRSKN, 2015)	From data: no industrial		x				Caribbeans	Latin Am.
Saint Lucia	2008-2010	(Masters, 2012)	Decision: < 12m (almost no industrial)		x				Caribbeans	Latin Am.
Saint Lucia	2010-2012	(Masters, 2014)	Decision: < 12m (almost no industrial)		x				Caribbeans	Latin Am.
Saint Lucia		(CRFM, 2008)	Decision: < 12m (almost no industrial)					Yes	Caribbeans	Latin Am.
Saint Vincent & the Grenadines	NA	-	No industrial	-					Caribbeans	Latin Am.
Samoa	1974 1976	(Philipp, 1977)	From data: all but tuna	Samoa a	x				Pacif. Isl.	Pacif. Isl.
Samoa	1991	(McCoy, 1991)	From data: all but tuna	Samoa a	x		x		Pacif. Isl.	Pacif. Isl.
Samoa	2003-2008	(Robert Gillett, 2011)	From data: all but tuna	Samoa a		x		Yes	Pacif. Isl.	Pacif. Isl.
Samoa	1992	(Robert Gillett, 2003)	From data: all but tuna	Samoa a	x				Pacif. Isl.	Pacif. Isl.
Samoa	2004-2010	(WCPFC, 2010a)	From data: all but tuna	Samoa a	x	x			Pacif. Isl.	Pacif. Isl.

Appendix 3 - Extended data sources and definitions used in Chapter 4 (Cont.)

San Marino	-	-	-	-	-	-	-	-	-	-	Not considered.
Sao Tome & Principe	1965	(Everett, 1976)	From data		x	x	x		Sub Saharan	Sub Saharan	
Sao Tome & Principe	1984	(Weber & Durand, 1986)	From data		x	x	x		Sub Saharan	Sub Saharan	
Sao Tome & Principe	1995 2003	(Oceanic Development, Poseidon Aquatic Resource Management Ltd, & MegaPesca Lda, 2004)	From data		x		x		Sub Saharan	Sub Saharan	
Saudi Arabia	1980 1995	(PERSGA, 2001)	From data	Saudi Arabia a	x	x	x		Middle East	Arab World	
Saudi Arabia	1997	(PERSGA, 2002)	From data	Saudi Arabia a	x	x	x		Middle East	Arab World	
Saudi Arabia	1965-1967	(FAO, n.d.-d)	From data	Saudi Arabia a	x		x		Middle East	Arab World	
Saudi Arabia	2002 2004	(FAO, n.d.-c)	From data	Saudi Arabia a	x	x	x		Middle East	Arab World	
Senegal	1981-1984	(Samba et al., 1984)	undecked pirogues, OB		x				NW Africa	Sub Saharan	
Senegal	1981-1982	(CRODT, 1982)	undecked pirogues, OB		x	x			NW Africa	Sub Saharan	
Senegal	1990-1991	(CRODT, 1994)	undecked pirogues, OB		x	x	x		NW Africa	Sub Saharan	
Senegal	1997-2015	(DPM, n.d.)	undecked pirogues, OB		x	x	x		NW Africa	Sub Saharan	
Senegal		(European Commission, n.d.)	undecked pirogues, OB	Senegal a				Yes	NW Africa	Sub Saharan	

Appendix 3 - Extended data sources and definitions used in Chapter 4 (Cont.)

Seychelles	1985-1995	(Payet, 1996)	undecked pirogues, OB		x	x	x		Sub Saharan	Sub Saharan
Seychelles	2009-2013	(Assan, Lucas, Socrate, & Holanda, 2014)	undecked pirogues, OB			x			Sub Saharan	Sub Saharan
Seychelles	2010-2014	(Assan, Lucas, Socrate, & Holanda, 2015)	undecked pirogues, OB			x			Sub Saharan	Sub Saharan
Sierra Leone	1965 1974	(Everett, 1976)	From data: pirogues/canoes	Sierra Leone a	x				NW Africa	Sub Saharan
Sierra Leone	1980	(Lawson & Robinson, 1983)	From data: pirogues/canoes		x		x		NW Africa	Sub Saharan
Sierra Leone	1997	(Horemans, 1998)	From data: pirogues/canoes		x				NW Africa	Sub Saharan
Sierra Leone	1995-2014	(FAO, 2011b, 2013, 2015c)	From data: pirogues/canoes	Sierra Leone b	x		x		NW Africa	Sub Saharan
Sierra Leone	2015	(MFMR, 2015)	From data: pirogues/canoes	Sierra Leone c		x			NW Africa	Sub Saharan
Sierra Leone	NA	(FAO, 2008c)	From data: pirogues/canoes					Yes	NW Africa	Sub Saharan
Singapore	1950-1967	(FAO, n.d.-d)	OB / < 5 GT	Singapore a	x	x	x		SE Asia	SE Asia/ Asia
Singapore	1976-2014	(SEAFDEC, n.d.)	OB / < 5 GT	SEAFDEC (5)	x	x	x		SE Asia	SE Asia/ Asia
Slovenia	1950-2015	(European Commission, n.d.)	< 12m and without towed gears.		x	x		Yes	Europe	Europe
Solomon Islands	1950	Estimate	-	Sol Isl. a	x	x			Pacif. Isl.	Oceania
Solomon Islands	1971	(FAO, 2009a; Oreihaka, 2001)	From data: anything not tuna	Sol Isl. a		x			Pacif. Isl.	Oceania
Solomon Islands	1991	(McCoy, 1991)	From data: anything not tuna		x		x	Yes	Pacif. Isl.	Oceania

Appendix 3 - Extended data sources and definitions used in Chapter 4 (Cont.)

Solomon Islands	1995-2000	(Oreihaka, 2001)	From data: anything not tuna	Sol Isl. a		x			Pacif. Isl.	Oceania
Solomon Islands	1995-2001	(Oreihaka, 2002)	From data: anything not tuna	Sol Isl. a		x			Pacif. Isl.	Oceania
Solomon Islands	2004-2009	(WCPFC, 2010b)	From data: anything not tuna	Sol Isl. a		x			Pacif. Isl.	Oceania
Solomon Islands	2003-2004	(Diake, 2005)	From data: anything not tuna	Sol Isl. a		x			Pacif. Isl.	Oceania
Solomon Islands	2009 2015	(Solomon Islands NSO, 2009)	From data: anything not tuna	Sol Isl. b	x				Pacif. Isl.	Oceania
Solomon Islands	2017	(WCPFC, n.d.-d)	NA			x		Yes	Pacif. Isl.	Oceania
Somalia	1950-2015	Estimate	All, no industrial	Somalia a		x			Sub Saharan	Sub Saharan
Somalia	1988	(PERSGA, 2001)	All, no industrial		x				Sub Saharan	Sub Saharan
Somalia	2005	(Kelleher, 2016)	All, no industrial		x		x		Sub Saharan	Sub Saharan
Somalia	2010	(Kulmiye, 2010)	All, no industrial	Somalia b	x				Sub Saharan	Sub Saharan
South Africa	1950-1966	(FAO, n.d.-d)	Decision: < 15 m	South Africa a	x	x	x		Sub Saharan	Sub Saharan
South Africa	2000-2014	(FAO, 2011b, 2013, 2015c)	Decision: < 15 m	South Africa a		x	x		Sub Saharan	Sub Saharan
Spain	1950-2015	(European Commission, n.d.)	< 12m and without towed gears.		x	x		Yes	Europe	Europe
Sri Lanka	1950-1967	(FAO, n.d.-d)	< 15m, no industrial trawl	Sri Lanka a	x	x	x		Indian Pen.	Indian Pen. / Asia
Sri Lanka	1995-2010	(FAO, n.d.-c)	< 15m, no industrial trawl	Sri Lanka a	x	x	x	Yes	Indian Pen.	Indian Pen. / Asia
Sri Lanka	1990-2012	(FAO, n.d.-b)	< 15m, no industrial trawl	Sri Lanka a	x	x	x		Indian Pen.	Indian Pen. / Asia

Appendix 3 - Extended data sources and definitions used in Chapter 4 (Cont.)

Sri Lanka	2008-2014	(FAO, 2011b, 2013, 2015c)	NA				x		Indian Pen.	Indian Pen. / Asia	
Sudan	1981	(M. J. Sanders & Morgan, 1989)	From data: all but trawl		x		x		Sub Saharan	Sub Saharan	
Sudan	1997	(PERSGA, 2002)	From data: all but trawl		x		x	Yes	Sub Saharan	Sub Saharan	
Sudan	2012	(Moreno & Herrera, 2013)	From data: all but trawl		x				Sub Saharan	Sub Saharan	
Sudan	2000-2005	(FAO, 2008b)	From data: all but trawl			x			Sub Saharan	Sub Saharan	
Suriname	NA	-	Decision: Generic< 12m, no trawl/seine	-					S America	Latin Am.	
Sweden	1950-2015	(European Commission, n.d.)	< 12m and without towed gears.		x	x		Yes	Europe	Europe	
Syrian Arab Rep.	1950-1981	(FAO, 1983)	From data: all but trawl		x	x		Yes	Middle East	Arab World	
Taiwan Prov. of China	1950-1955	(FAO, n.d.-d)	Decision (Korea, Japan): <10 GT	Taiwan a	x	x	x		NE Asia	NE Asia/Asia	Est. independently
Taiwan Prov. of China	1956-2015	(Fishery Agency, n.d.)	Decision (Korea, Japan): <10 GT		x	x	x	Yes	NE Asia	NE Asia/Asia	Est. independently
Tanzania, United Rep. of	2002-2010	(FAO, n.d.-c)	From data: OB	Tanzania a		x		Yes	Sub Saharan	Sub Saharan	
Tanzania, United Rep. of	1990-2003	(Abdallah, 2004)	From data: OB			x			Sub Saharan	Sub Saharan	
Tanzania, United Rep. of	1998	(Shao, Mlay, & Mushi, 2003)	From data: OB		x				Sub Saharan	Sub Saharan	

Appendix 3 - Extended data sources and definitions used in Chapter 4 (Cont.)

Tanzania, United Rep. of	2001	(Jiddawi & Öhman, 2002)	From data: OB		x				Sub Saharan	Sub Saharan
Tanzania, United Rep. of	2013	(FSS, 2014)	From data: OB		x	x	x		Sub Saharan	Sub Saharan
Tanzania, United Rep. of	2009	(MALF, 2016)	From data: OB		x	x	x		Sub Saharan	Sub Saharan
Thailand	1950-1967	(FAO, n.d.-d)	< 10 GT (including OB powered)	only I, UP unreliable		x			SE Asia	SE Asia/ Asia
Thailand	1967 1970-1982	(Panayotou & Jetanavanich, 1987)	< 10 GT (including OB powered)		x		x		SE Asia	SE Asia/ Asia
Thailand	1976-2014	(SEAFDEC, n.d.)	< 10 GT (including OB powered)	SEAFDEC (5)					SE Asia	SE Asia/ Asia
Thailand	2000	(NSO, 2001)	< 10 GT (including OB powered)	only OB and UP	x		x		SE Asia	SE Asia/ Asia
Thailand	NA	(DoF Thailand, 2015)	< 10 GT (including OB powered)	Thailand a				Yes	SE Asia	SE Asia/ Asia
Thailand	1985 1995	(Poonnachit-Korsieporn, 2000)	< 10 GT (including OB powered)	Thailand a	x	x	x		SE Asia	SE Asia/ Asia
Thailand	2013	(NSO, 2013)	< 10 GT (including OB powered)	only OB and UP	x		x		SE Asia	SE Asia/ Asia
Thailand	NA	(WCPFC, n.d.-d)	NA					Yes	SE Asia	SE Asia/ Asia
Timor-Leste	1950-2015	Estimate	All, no industrial	Timor a		x			SE Asia	SE Asia/ Asia
Timor-Leste	2009	(FAO, 2009b)	All, no industrial		x		x		SE Asia	SE Asia/ Asia
Timor-Leste	1966 1999-2000 1950-2015*	(Alonso, Wilson, Rodrigues, Pereira, & Griffiths, 2013)	All, no industrial		x			Yes	SE Asia	SE Asia/ Asia

Appendix 3 - Extended data sources and definitions used in Chapter 4 (Cont.)

Timor-Leste	2012	(Tsujimura, Alonso, Amaral, & Rodrigues, 2012)	All, no industrial		x		x		SE Asia	SE Asia/ Asia
Togo	1980	(Lawson & Robinson, 1983)	From data: canoes		x		x		Sub Saharan	Sub Saharan
Togo	1984	(Weber & Durand, 1986)	From data: canoes		x	x			Sub Saharan	Sub Saharan
Tonga	2000-2014	(WCPFC, n.d.-a)	From data: anything not tuna	Tonga a		x			Pacif. Isl.	Pacif. Isl.
Tonga	2017	(WCPFC, n.d.-d)	From data: anything not tuna						Pacif. Isl.	Pacif. Isl.
Trinidad & Tobago	1980	(La Croix, 1984)	From data: pirogues, no longline/trawls		x	x		Yes	Caribbeans	Latin Am.
Trinidad & Tobago	1991	(Project GloBAL, 2007)	From data: pirogues, no longline/trawls		x			Yes	Caribbeans	Latin Am.
Trinidad & Tobago	2002	(FAO, 2006b)	From data: pirogues, no longline/trawls		x	x			Caribbeans	Latin Am.
Trinidad & Tobago	1998	(FAO, 2000a)	From data: pirogues, no longline/trawls		x	x		Yes	Caribbeans	Latin Am.
Trinidad & Tobago	2006	(FAO, 2006a)	From data: pirogues, no longline/trawls		x	x		Yes	Caribbeans	Latin Am.
Tunisia	1950-1966	(FAO, n.d.-d)	From data: all but trawls and tuna fisheries	Tunisia a		x			Maghreb	Arab World
Tunisia	2001-2015	(INS, n.d.)	From data: all but trawls and tuna fisheries		x	x	x		Maghreb	Arab World
Turkey	1970-2014	(Yılmaz, Bilgin, & Olguner, 2017)	From data: <20m	Turkey a	x				Middle East	Arab World

Turkey	1990	(Özdamar, 1995)	From data: <20m			x		Yes	Middle East	Arab World	
Turkey	2000-2015	(TUIK, n.d.)	From data: <20m		x	x			Middle East	Arab World	
Turkmenistan	-	-	-	-	-	-	-	-	-	-	Caspian Sea only
Tuvalu	1982-2007	(FAO, 2010c)	From data: skiffs	Tuvalu a		x			Pacif. Isl.	Pacif. Isl.	
Tuvalu	1991	(McCoy, 1991)	From data: skiffs		x		x		Pacif. Isl.	Pacif. Isl.	
Tuvalu	2016	(Tuvalu Fisheries, 2017)	From data: skiffs	Tuvalu a	x	x	x		Pacif. Isl.	Pacif. Isl.	
Ukraine	1950-1993	(Beaudry & Folsom, 1993)	From data: 80GT/ < 55kW (similar Russia)	Ukraine a		x			Europe	Europe	
Ukraine	2011	(Shivarov, 2013)	From data: 80GT/ < 55kW (similar Russia)		x	x			Europe	Europe	
Ukraine	1950-2010	Estimate	From data: 80GT/ < 55kW (similar Russia)	Ukraine b	x				Europe	Europe	
United Arab Emirates	1976-1998	(Ahmad & Al Janahi, 1999)	From data: no industrial	UAE a	x				Middle East	Arab World	
United Arab Emirates	2000-2005	(MOCCAE, n.d.)	From data: no industrial	UAE a	x				Middle East	Arab World	
United Arab Emirates	2005-2013	(FCSA, 2017)	From data: no industrial	UAE a	x				Middle East	Arab World	
United Kingdom	1950-2015	(European Commission, n.d.)	< 12m and without towed gears.		x	x		Yes	Europe	Europe	
United States of America	1950-1970	(United States Census Bureau, 1975)	From data: < 5 net tons / motorboats.		x	x	x		N America	N America	

Appendix 3 - Extended data sources and definitions used in Chapter 4 (Cont.)

United States of America	1972 1974 1976 1978 1981 1983 1984 1987 1988 1990-1993 1996-1999	(NOAA, n.d.)	From data: < 5 net tons / motorboats.		x	x	x		N America	N America	
United States of America	2016	(Homeport Security, 2017)	From data: < 5 net tons / motorboats.			x			N America	N America	
United States of America	2016	Estimate	From data: < 5 net tons / motorboats.	USA a	x			Yes	N America	N America	
Uruguay	1998	(INAPE, 1999)	< 10 GRT		x	x	x	Yes	S America	Latin Am.	
Uruguay	1999-2015	(MGAP - DINARA, n.d.)	< 10 GRT		x	x	x	Yes	S America	Latin Am.	
Vanuatu	1950	Estimate	From data: All not tuna	Vanuatu a	x	x			Pacif. Isl.	Oceania	
Vanuatu	1991	(McCoy, 1991)	From data: All not tuna		x		x		Pacif. Isl.	Oceania	
Vanuatu	2000-2015	Estimate	From data: All not tuna	Vanuatu b	x				Pacif. Isl.	Oceania	
Vanuatu	2002-2015	(WCPFC, n.d.-c)	From data: All not tuna			x			Pacif. Isl.	Oceania	
Vatican (Holy Sea)	-	-	-	-	-	-	-	-	-	-	Not considered.
Venezuela	1952-1967	(FAO, n.d.-d)	< 75hp/OB	Venezuela a	x	x	x		S America	Latin Am.	
Venezuela	1996-2012	(FAO, n.d.-b)	< 75hp/OB	Venezuela a		x			S America	Latin Am.	

Appendix 3 - Extended data sources and definitions used in Chapter 4 (Cont.)

Viet Nam	1980	(FAO, 2004c)	< 45hp	Viet Nam a	x	x		Yes	SE Asia	SE Asia/ Asia
Viet Nam	1961-1966	(FAO, n.d.-d)	< 45hp	Viet Nam a	x	x	x		SE Asia	SE Asia/ Asia
Viet Nam	1981-1998 2015	(SEAFDEC, n.d.)	< 45hp	Viet Nam a SEAFDEC (3)	x	x			SE Asia	SE Asia/ Asia
Viet Nam	1990-2011	(DoF, n.d.)	< 45hp	Viet Nam b	x	x			SE Asia	SE Asia/ Asia
Viet Nam	2010 2012-2014	(GSO, n.d.)	< 45hp	Viet Nam c				Yes	SE Asia	SE Asia/ Asia
Viet Nam	NA	(DERG - CIEM, 2010)	< 45hp		x	x		Yes	SE Asia	SE Asia/ Asia
Viet Nam	1998	(Son et al., 2003)	< 45hp		x	x	x	Yes	SE Asia	SE Asia/ Asia
Yemen	1998	(FAO, 2002a)	from data: OB / < 12m	Yemen a	x	x			Middle East	Arab World
Yemen	1959-1965	(FAO, n.d.-d)	from data: OB / < 12m	Yemen a	x	x	x		Middle East	Arab World
Yemen	2005 2008	(FAO, n.d.-c)	from data: OB / < 12m	Yemen a	x	x		Yes	Middle East	Arab World

Appendix 4 – Extended list of data pre-processing methods used in Chapter 4, with reference to Appendix 3.

Algeria a: Only 1965 is retained, as being the only year that has both outboard (considered artisanal) and inboard (considered industrial).
Algeria b: Trawls, Purse Seine, Tuna and Coral vessels are considered industrial, as per indication from the Ministry website. Artisanal is removed as considered underestimated.

Angola a: a 0 point for artisanal fisheries in 1950 and 3000 in 2013 based on FAO (FAO, 2011b, 2011a, 2013, 2015c) are estimated, to start and end the fitting.
Angola b: It Is considered that all vessels given by the FAO global handbook are industrial, and very likely Portuguese fishing vessels, which disappeared after the 1975 independence.
Angola c: Data from the FAO DB 70 seems to overestimate the number of vessels. To be taken cautiously.

Australia a: The year books 1906-1978 give the total number of fishing vessels, as well as the ratio of unpowered vessels to a subset, considered representative of the whole fleet. Kailola et al. (1993) give the proportion of vessels under 10m for 1990 and 1965, 2 dummies are given for 1914 (90%) and 2015 (50%) with a sigmoid decrease.
Australia b: The number of vessels given by the Australian General register of ships (www.amsa.gov.au) is considered underestimated, as only vessels over 24m or fishing in the high seas are required to register. On the other hand, using data from fisheries licences alone leads to extreme overestimates, as it does not consider vessels fishing in multiple fisheries (common in Australia). The number of vessels was estimated as the halfway point between these 2, although this is a probable overestimate due to recent and large-scale buyback schemes. As a consequence, the average power per vessel might be underestimated.

Bahamas a: The data (industrial) for 1994 (from census) is twice that of FAO. We considered the industrial in 2012 to be underestimated. Although the fleet of the Bahamas is mostly artisanal in nature, we considered 6m as the limit for industrial.

Bangladesh a: The artisanal and unpowered fleets are given unrealistically constant for many years. Only the first value of each of these years is kept, the rest is considered a repetition of the reporting.

Belize a: The data from official source for the artisanal fleet seems to have gone down since the 1980s, while OSPESCA indicates they have gone up. It is possible that some vessels are not reported in the national statistics (outboard vessels for instance) and the results should be taken cautiously.
Belize b: The greatest effort has been carried out to exclude flags of convenience from the analysis.

Benin a: The FAO data includes non marine fisheries for the unpowered fleet, and is removed.

Brazil a: 1958 is chosen as 0 for industrial, as the sector started in 1959.
Brazil b: The data recognises that industrial fishing is probably under-reported and some industrial vessels reported in artisanal.

Cambodia a: The marine unpowered fleet seems extremely underestimated, but upper numbers include the Mekong river and Tonle Sap lake fisheries, which should be the majority of the unpowered fishing fleet. We kept the lower estimates, which show an approximate linear decrease in number since the 1980s.

Cameroon a: Only one data point for artisanal and unpowered in 1987.

Canada a: Some years removed as being underestimated (partial reporting).
Canada b: The threshold for artisanal/industrial is chosen at 20GT, in line with some reports, and giving an approximate maximum LOA of 12.5m (close to EU 12m). Historically, there are references for 10GT, but no legal or institutional support.
Canada c: A subset of the register (fishing vessels, data in metric) allows for a link between GT, LOA and power.

Chile a: The data from the FAO handbook is classified by GT class, which might differ from the > 50GRT used (although comparison with recent registry indicate that the difference is minimal, if existing). All data > 50GT per vessel is considered industrial, with the error stemming from the data of unknown tonnage. 1964 only has industrial. Power only for 1966/1967. The data for artisanal is used only as comparison, as aggregating lancha (outboard) and bote (inboard) and seemingly reporting only the active ones some years.
Chile b: The industrial data contains a mix of vessels registered, vessels registered >50GRT, vessels used, vessels used > 50GRT. Whenever possible, the number of vessels registered is used, as being the highest number and more representative of the fleet capacity than the vessels used. Some data contradict each other, in particular the industrial in the 1960s seems high. What is available indicates that the industrial peaked in the 70s, but the uncertainty in data is high, due to the dictatorship (1973-1990).
Chile c: The artisanal data is separated in lancha and bote, which are reconstructed separately. The data from the RPA (2004 onwards) seems to only cover part of the fleet, while the BEM (1999 onwards) is more complete. The FAO data contains only one data point (1955) with both lancha and bote (referred as under 5 t motorised and motorboats) There is a factor 10 difference in the unpowered fleet active vs existing, and factor 2 for the Artisanal, data is subject to extreme caution.
Chile d: The FAO database and the register of artisanal vessels both give partial information of the power per vessel of different length, type and tonnage classes. The data (industrial and artisanal) is separated by type (gear, type of vessel), length (LOA) and GT categories, and the corresponding power per vessel is associated.

China a: The data was separated in time series based on type of fleet (marine wild catch was the only considered) and power of motor using sigmoid fitting. The average power of each time series was linked to GT based on linear correlation found in data from the WCPFC Record of Fishing Vessels. Vessels under 10GT were considered artisanal.

Colombia a: All vessels with inboard motors are considered industrial, which may lead to overestimates in the 1960s. only 4 data points for the powered fleet 1962-66.
Colombia b: An estimated 0 industrial vessels is given for 1950 to start the fitting.
Colombia c: estimates of artisanal fishing vessels based on the states which have access to the sea. This might be a slight overestimate, as river/lakes vessels might be included.

DRCa: The DRC is one of the few cases where there is little to no powered marine fisheries. The sector was non-existent till at least 1984, and seemed to have barely risen, due mostly to the narrow coastline. We considered the motorised artisanal sector to be null.

Cuba a: There is little data on the difference between artisanal and industrial fleets, with the FAO not naming the sectors. When no other information available, it was assumed that lower numbers

were the industrial fleet and higher the artisanal motorised. Most data for Cuba is shrouded in underestimates, underreporting and cold-war secrecy.
Cuba b: The CIA reports that 900 boats were aimed for by Cuba by 1970. We dummied that number as reached in the mid 1970s. A dummied 0 is fixed for the industrial fleet, to start the fitting.

Djibouti a: Estimated 0, considering that no evidence of motorisation was found till the 1990s.
Djibouti b: Only 2 trawlers operate off the shore of Djibouti in 2014. No evidence was found of them till the 2000s, we considered they started in 2005.

Ecuador a: The total number of motorised vessels is given in the FAO global handbook. The numbers are consistent with both the total number of vessels and industrial vessels only. We chose to assume that the vessels reported to the FAO were industrial only, as it is a common bias in national reporting.
Ecuador b: The number of Artisanal vessels is highly uncertain. Cedeno (n.d.) reports data for both motorised and unmotorized (approx. 32000/14500) without giving a year. Pinoargote (2008) report a number of 10721 motorised artisanal, but only the vessels registered. Martinez-Ortiz et al. (2015) give a number of 45793, referring to the census (SRP 2014), but does not specify whether this include unmotorized. We chose to give an estimate of 10000 in 2000, considering the data from 2006 to be an underreporting, and of 45793in 2013. This value is probably overestimated as including unpowered. The FAO DB 70 and 80 are very inconsistent in their reporting of smaller vessels, although the number of industrial agree with other sources.

Egypt a: The number of vessels in some of the databases might include vessels on the Nile valley/delta. While the Red Sea fleet is given separately, the number of vessels on the Mediterranean Sea is uncertain.

Eq. Guinea a: Dummy industrial. The industrial reported by the FAO database seem to include flags of convenience and vessels with access rights. The FAO vessel finder reports 7 vessels in 2017, 4 of which have Chinese names. We considered only 3 industrial vessels (since 1984) in the fleet, all other being flags of convenience.

Eritrea a: Dummied 0 artisanal, considering motorisation occurred through the 1960s (FAO, 1993).
Eritrea b: No industrial is considered, as most (if not all) vessels are foreign vessels with temporary licenses.

Fiji a: the number of vessels in the industrial fishery is subject to caution, due to flags of convenience and a reporting of only the active vessels.

Gabon a: 111 industrial vessels are considered in Gabon waters, of which 35% landing in locally. These are considered the industrial fleet, the rest is flag of convenience and/or agreements.

Georgia a: 2 dummied points are created for the artisanal fleet, based on population increase, to start the fitting.
Georgia b: There is uncertainty as to when exactly Georgia reached this number of vessels (season 2008-2009), so the number was chosen as the 31 Dec 2007.
Georgia c: Based on (D. Sanders, 2014), the fishing fleet of Georgia was almost entirely sold in the early 90s. We considered 5 vessels in 1994, with an increase up to 37 in 2007.

Ghana a: Reporting of the pirogues and their classification is inconsistent. The engine power is for the industrial/semi industrial only.

Greenland a: The various DB give only the artisanal with a licence to fish. According to Berthelsen (2014), there are an extra 1500 unreported motorised dinghies in the artisanal fishery in 2010-2012. This number is added to the various stats, with a population ratio. The number of artisanal unpowered fishing vessels is subject to extreme variability, as between 1000 (FAO) - 5000 (ICES) small boats are estimated. FAO data often contradicts itself, to be taken cautiously. **Greenland b**: Dummied 0 for the industrial fishing, based on the idea that the fleet was built through the 1960s (ICES, 2004).

Grenada a: There is no clear definition of what artisanal fisheries are, although it is implied that most of Grenada's fisheries are artisanal, with the exception of the longline (tuna) fishery. We chose this as demarcation, with longline tuna vessels > 12m considered industrial in the FAO DB. Data from CRFM in 2011-12 contradicts data from previous years. It is possible that unpowered vessels are included in the reporting for these years.

Guatemala a: The census defines artisanal as using sails and oars, and small scale as using outboard engines. We used this definition in the other DB, although we called them "artisanal motorised" and "unpowered".

Guinea a: Domain (1999) gives a number of industrial vessels, but this would be mostly international vessels allowed to fish in Guinean waters. Instead, the book refers to "advanced artisanal", which fits the legal definition (i.e. using mechanised gears and/or conservation methods besides salt and ice).

Guyana a: The industrial fisheries consist of shrimp/seabob trawlers and (snapper) deep sea longline. As different reports focus on different aspects, the 2 data series are reconstructed separately.

Honduras a: The FAO DB seem to be mixing artisanal, industrial, inland and marine waters. Only a few data points were considered for the power of the fleet and to start the fitting of the industrial fleet.
Honduras b: Dummied 0 for the motorised artisanal fleet to get the fitting started. **Honduras c**: Being the only such data reported by the fishery department and other institutions, it is assumed that the shrimp fishery is the industrial one. It might lead to underestimates of the industrial fleet.

Iceland a: The FAO DB give the number of vessels separated by length class, not GT. From the Statice data, we assumed the ratio of vessels < 12m and < 25GT in the FAO DB to have stayed at similar levels up till 1999.

India a: Some data given is not national and are missing the regions of Goa, Adaman and/or Lakshadweep (approximately 2% of the fleet, 2010 data). The missing parts are estimated as a ratio of the data found. The separation of Industrial is given as "mechanised". In 1980, the state of Maharashtra is missing, representing 25% of the powered fleet and 7% of the un motorised one.
India b: The data does not make the distinction between motorised and not motorised. It gives an order of magnitude for the fleet, but no data point.
India c: only used as a reference point, as the text refers to "in the early 90s" but not the exact year.
India d: 2000 artisanal and industrial given in data from MoA. Data for 1998 refer to the optimum fleet size. Data from 2012 is given but the year is unclear, used only as reference point.

India e: The presentation links the average LOA and engine power of different gear. Every data point is separated by gear (proportionality by region applied if the data is missing information) and the average engine power is applied.

Indonesia a: The FAO data for the powered vessels is assumed to be the total of inboard and outboard powered vessels. The decomposition by GT category is done by sigmoid fitting and extrapolating to 1957, normalised to the total number of vessels given by the FAO.

Iran a: The number of Artisanal vessels is approximate, as only the total number of vessels or a rough estimate is given in the documentation.

Iraq a: Dummied 0 for the motorised fleet in 1950 to start the fit.

Israel a: The industrial fisheries consist of trawlers, purse seines and deep sea longline (grouped as pelagic fisheries). As different reports focus on different aspects, the data series are reconstructed separately.

Kenya a: Less than 10% of the fleet is considered motorized in 1979.

Kiribati a: Artisanal boats after 2010 are based on the 2010 survey and excluded, as we did our own estimates. Only the national tuna fleet is considered in the estimates, many flags of convenience are reported.

Korea a: The number of vessels of each GT class is extrapolated separately, normalised to the total number of vessel for 1985 and 1951-1953.

Madagascar a: The DB do not precise what the vessels are. It is possible that some of the industrial vessels belong to European countries in earlier years.
Madagascar b: Very few data is available for the number of artisanal vessels. Some dummied points were created following a ratio to population to avoid a linear extrapolation.

Malaysia a: The data after 1984 is fully given and decomposed by power class. Between 1969 and 1984, the decomposition is given only for Peninsular Malaysia, the decomposition for the islands is considered proportional as that of Peninsular Malaysia. Prior to 1969, only Peninsular Malaysia (Malaya) is given, and without decomposition. The ratio of the fleet of Malaya to the whole of Malaysia prior to 1968 is considered the average of the ratio 1968:1980. The Decomposition by power class for this year is given as a sigmoid extrapolation of available data. This method increases the uncertainty for unpowered and artisanal (Malaya's share is approximately 70% and 50% respectively) but relatively low for industrial (over 80% of the inboard is in Malaya, and over 97% of the industrial >40HP).

Marshall Isl. a: Estimated 0, considering that OB engines were introduced in the 60s.
Marshall Isl. b: Estimated artisanal based on population growth.

Mexico a: uncertainty on the unpowered/powered for vessels less than 1NT. We considered what is <1NT to be unpowered up till the 1970s (comparable results with FAO). Only a few years (1979-1988) are separated by GT class, the rest is given as "ribeñera" (coastal) and "altura" (deep sea). The FAO global handbook is used as comparison, while the FAO DB 80 is used as source of power by GT class. The data from the yearbook (anuario) is given in net tons and was converted to GT. Please note that the yearbook of fisheries has changed names over the years (fisheries, fisheries and aquaculture, …) and author (as has the department of fisheries).

FSM a: Estimated 0, considering that OB engines were introduced in the 60s.
FSM b: Estimated artisanal based on population growth.

Montenegro a: The FAO country profile is for both Serbia and Montenegro. Considering that the Serbian access to the sea is minimal, we assumed the whole fleet to be from Montenegro.

Morocco a: Moroccan data is (usually) separated in artisanal, coastal and dep sea fisheries, each separated in further sectors based on their targets/gears. We found easier and more accurate to keep the gear separation and reconstruct each sector as an independent time series of both vessels and power).

Mozambique a: The database does not specify whether the fleet is artisanal or industrial. From further data, the ratio artisanal/motorised is close to 60%.

Myanmar a: Many data points from different sources. The data is generally the same order of magnitude, the maximum is chosen. The data is separated by GT class and the average power is given by FAO DB 80. The artisanal power is considered under 12hp (9kW) from (SEAFDEC, 2017), given an average of 7 kW

Namibia a: Officially, there is no artisanal fisheries in Namibia. A report (Batty et al., 2005) estimates 15-20 artisanal vessels, without indication of whether unpowered or not. The whole sector is dummied.

New Zealand a: in recent years, only the motorised trawls are depicted, which we considered industrial. In the FAO DB, the vessels > 15m give similar results. It is possible that the number of industrial vessels is overestimated this way in 50s and 60s.

Nigeria a: The number of unpowered vessels in Nigeria are given constant in most DB after the 80s, probably due to misreporting.

Norway a: Extracts of the Norwegian registry of vessels are associated with the length of vessels to find the average engine power of vessels.

Oman a: The fisheries statistics refer to certain vessels (dhows) as being artisanal, while other are just "boats". We considered all longlines and coastal to be industrial, while the rest is artisanal. It is possible that some unpowered vessels were included in the data.

Palau a: The data specifies that the engine power of artisanal vessels is > 70hp, without more precision. We chose an average of 100hp engines for that year.
Palau b: Dummied artisanal, based on population growth.

Panama a: The FAO DB seem to include some vessels from inland waters, and are used for comparison and estimate the power of the fleet, assuming that vessels are similar.

PNG a: Dummied 0, considering that OB engines were introduced in the 60s.
PNG b: The text refers to 3000 motors imported per year, giving estimates for 1989 and 1990.
PNG c: the number of tuna/ shark vessels from PNG is uncertain, due to chartered vessels landing in other countries. Whenever possible, only the national tuna and shark fisheries are included in the industrial fleet.
PNG d: Estimated artisanal based on population increase since 1991.

Peru a: Most of the information for the industrial sector contradict itself from one year to another, as the focus is on the active anchoveta fleet. When different data is available, the highest number is chosen as representing the full industrial fleet (active and not, anchoveta and other fisheries). Data after 1964 is considered only as error margin, as reporting only the active declared anchoveta fleet.
Peru b: The 2012 yearbook contains artisanal and unpowered fleets as well, the other years only industrial.
Peru c: The registry of vessels gives the engine power, LOA and gross tonnage of ships for 2016. The data for other years is separated by GT class and an average power of the GT class is given based on the registry.

Philippines a: unpowered, municipal (powered, < 3GT) and commercial (Powered, >3GT) are interpolated separately from the data source. Wherever possible, the ratio of commercial vessels follows that of the data. Prior to 1989, the ratio of various GT classes is given as an average of the ratios 1972-1975 (only years with complete dataset). Post 1989, the ratio is given as an average of the ratio for 1989 and 2016 (with error).
Philippines b: The data point contradicts the general trend of other data, probably due to being a partial aggregate of the Philippines Regional Fisheries Office. The point is used only as an estimate of the error in the reconstruction of the number of vessels.

Qatar a: The number of vessels in the Qatar fisheries has been capped at 515 since 1998 (no more licenses issued)

Russia a: Prior to 1991, the data was reported for the USSR, not specifically for what will become the Russian Federation. A NOAA report (Sealy, 1974) gives the catch of the USSR countries, we assumed that the ratio of the Russian fleet to the USSR was the same than the ratio of the catch (approx.. 70%). Data from VNIRO (2015) indicate that the Russian fleet should be between 50-60% of USSR, which is used as error.
Russia b: The vessels >100 GRT for 1993 is considered the number of vessels imported by the Russian Federation from 1951-1993.
Russia c: The data gives the number of vessels >55kW considered industrial. As most of the Russian fleet is outdated and over 20 years old (VNIRO 2015), it is considered that >100GRT and >55kW are equivalent in the Russian fleet. Considering only the capture fleet, outside of floating processing facilities and transport.
Russia d: The data gives the total number of vessels for the USSR. The artisanal fleet of Russia is considered the difference between the given total of USSR and the reconstructed industrial, times the ration of Russia/USSR, as per Russia a.
Russia e: Most data can be separated into GT classes, we used the FAO database to make a link between the average GT per vessel and the average Power per vessel.

Samoa a: In 1991 a cyclone devastated Samoa, reducing the artisanal fleet down to 40 vessels. The data is reconstructed in 2 series, before and after the cyclone, both following a sigmoid fit.

Saudi Arabia a: The data does not make the distinction between powered and unpowered. Considering that the DB in the 50s and 60s give a 2/3 ratio motorised to total artisanal, we considered the motorisation to reach 50% in the 2000s. Industrial fishing did not start till the 80s, all data prior is considered artisanal.

SEAFDEC: Southeast Asian Fisheries Development Center (SEAFDEC, n.d.). The following modifications have been applied:

- Indonesia: 1981 removed as duplicate of 1982. Years 1986, 1991, 1992, 1997, 2008, 2009 removed as either the total number of vessels or the decomposition in tonnage class blatantly contradicts the rest of the data (misclassified).
- Philippines: 1976-1988 for the decomposition by GT class. The totals contradict other data given for the country and contribute to higher uncertainty.
- Viet Nam: 1981-1998 and 2015, total number of motorised vessels.
- Myanmar: Data is contradictory but of the same order than other sources. The power of artisanal is given by (SEAFDEC, 2017)
- Singapore: 1976-2014, removing 1987 industrial, as the data seems extremely underestimated. The industrial data for 2013-2014 seems to be overestimated, we kept the number of vessels from 2009 (3 vessels).
- Brunei-Darussalam: 1976-2012. The unpowered fleet is taken only as reference only.

Senegal a: The different data from the CRODT/DPM give the tonnage class of the industrial fleet, linked to the engine power through vessels of the EU fleet register.

Sierra Leone a: The number of vessels in 1974 seems to have a typo, used 140 instead of 1400.
Sierra Leone b: from the FAO country profile, it is implied that the industrial fisheries did not start till 2008, all data prior is considered artisanal. The data after 2010 is probably underestimated.
Sierra Leone c: The data come from mid year, underestimating the number of vessels at the end of the year.

Singapore a: Prior to 1968, the data is aggregated in OB/IN. The FAO data is desaggregated based on the average ratio from SEAFDEC data.

Sol Isl. a: Data from the tuna fishery is contradictory. The highest value of each year (removing flags of convenience) is taken. FAO country profile states that tuna fisheries started in 1973, while the SCTB in 1972. Both industrial and artisanal are fixed at a dummied 0 in 1950.
Sol Isl. b: From the census 2009 (Solomon Islands NSO, 2009), there were 6103 outboard motors in the country, and 66% of the households involved in fishing. We estimate about 4000 outboard fishing vessels for 2009, and an increase for 2015 proportional of that of the population.

Somalia a: Estimated 0 industrial. Some reports indicate a fishing fleet in the 1970s in association with the USSR, but it is considered part of the USSR fleet and ignored.
Somalia b: The report is focused only on Puntland, but it is assumed that it represents the majority of the motorized fleet.

South Africa a: Only partial data is available some years (removed). The data since 2000s is considered industrial, as being only a portion of the artisanal in the 60s.

Sri Lanka a: In the 1960s, only the data reported as “motorised trawlers” is considered industrial (considered the only non-traditional fishing vessels). In later years, a few non-trawlers >15m are added to this.

Taiwan a: each category of vessels (GT class) extrapolated linearly prior to 1956 from the data 1956-1959.

Tanzania a: The FAO DB aggregates the artisanal inland and marine fisheries, and the data is not used as a consequence.

Thailand a: Data is contradictory, and only the maximum values of each year are taken, particularly for the unpowered fleet. DoF 2015 is only used as a reference point, as the data is mid-year. The data is decomposed by GT class (partial data from SEAFDEC), then linked to power with WCPFC.

Timor a: No industrial is considered in Timor-Leste.
Timor b: The document hints at the stagnation of the fleet during the 70s and destruction of the fleet after independence from Indonesia. The artisanal fleet is considered to increase up till the 70s, follow by stagnation, decrease in 1999 and reconstruction.

Tonga a: The data refers to joint ventures, which are excluded from Tonga's data.

Tunisia a: The data for artisanal seems overestimated and not in line with further data. It is very possible that some of the French fleet was reported alongside the Tunisian one prior to independence.

Turkey a: The number of industrial vessels is approximated, based on vessels > 18GT and the black sea fishing fleet.

Tuvalu a: There is confusion about what is considered Tuvalu national industrial fleet. The FAO profile considers none, while the department of fisheries a handful of vessels (mostly older vessels donated by Korea and Japan), although they could be flags of convenience, and virtually none of the catch is landed in Tuvalu. We considered this handful of vessels to be part of the Tuvalu fleet.

Ukraine a: The industrial vessels are considered to increase from 0 in 1950 with each import. **Ukraine b**: It was assumed that the number of artisanal vessels peaked in the 80s (similar to Russia and most European fleet). The artisanal fishing fleet is dummied based on the ratio to Ukrainian population.

UAE a: The vessels reported by the government might be under estimated as being only the licensed ones. One the other hand, data by Ahmad & Al Janahi might include some unpowered fleet. The difference makes for a large uncertainty.

USA a: Data point constructed for artisanal vessels, assuming the artisanal Alaskan fleet as reference. The ratio of artisanal vessels in Alaska to the total number in the USA is assumed constant. For the years 1990-2012, the ratio of Alaska/USA has averaged 18%. Data source for Alaska from https://www.cfec.state.ak.us/plook/#downloads

Vanuatu a: Estimated 0 for the artisanal and industrial motorised, fleet, considering that no local tuna fishery existed, and that motorised skiffs were introduced with the village fishery development programme in the 80s.
Vanuatu b: Only one data point is found for the artisanal fishery (1991). The rest is based on population growth.

Venezuela a: The data classified >5GT is considered inboard (industrial) while the rest artisanal (1952). Data in the FAO DB 70 is entirely industrial, the artisanal fleet is considered the difference between the total and industrial after extrapolation of the latter.

Viet Nam a: The data is separated and extrapolated in power classes, with 45hp used as the limit between artisanal and industrial.
Viet Nam b: The data might contain a mix of powered and unpowered vessels, and some years

must be taken cautiously, particularly the later years.
Viet Nam c: The data contains only vessels of power > 90hp (therefore only a part of the industrial fleet) and is used only to determine the engine power of these vessels.
Yemen a: Legally, artisanal is under 20m/ 150HP. It seems like the industrial is underdeveloped and dominated by international fleet. We considered industrial to be inboard motors, by opposition with outboard engines.

Appendix 5 – Data points and associated errors in reconstructing the fleet size, per country as per Chapter 4

Country	ISO3	Number of Data points			Year of first data			Year of last data			Number of interpolation - sigmoid fit			Average error - sigmoid fit (ratio to 1)			Data based on population growth (increase) or motorisation (decrease) - Unpowered only	Years extrapolated by ARIMA models					
		Art.	Ind.	Unpow.	Art.	Ind.	Unpow.	Art.	Ind.	Unpow.	Art.	Ind.	Unpow.	Art.	Ind.	Unpow.		Artisanal		Industrial		Unpowered	
Albania	ALB	6	50	1	1960	1960	2003	2015	2015	2003	50	6	0	0.096	0.056	-	65	1959	-	1959	-	-	-
Algeria	DZA	12	13	6	1965	1965	1965	2009	2010	2011	33	33	41	0.035	0.04	0.16	0	1964	2015	1964	2015	1964	2015
Angola	AGO	7	19	24	1950	1950	1950	2013	2009	2012	57	41	39	0.061	0.119	0.066	0	-	2015	-	2015	-	2015
Antigua and Barbuda	ATG	19	11	9	1958	2000	1958	2011	2010	2015	35	0	0	0.082	-	-	57	1957	2015	1999	2015	-	-
Argentina	ARG	34	50	5	1961	1961	1995	2006	2010	2005	12	0	0	0.077	-	-	61	1960	2015	1960	2015	-	-
Australia	AUS	6	6	58	1914	1914	1914	2014	2014	2014	61	61	37	0.006	0.003	0.109	0	-	2015	-	2015	-	2015
Azerbaijan	AZE	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Bahamas	BHS	4	9	8	1960	1958	1958	2015	2012	1994	52	46	29	0.015	0.052	0.028	0	1959	-	1957	2015	1957	2015
Bahrain	BHR	13	8	-	1950	1965	-	2012	1998	-	50	26	-	0.057	0.055	-	-	-	2015	1964	2015	-	-
Bangladesh	BGD	18	43	18	1973	1973	1968	2015	2015	2015	25	0	30	0.289	-	0.06	0	1972	-	1972	-	1967	-
Barbados	BRB	28	12	12	1950	1950	1955	2010	2010	1967	33	49	0	6.455	0.04	-	54	-	2015	-	2015	-	-
Belgium	BEL	66	66	7	1950	1950	1950	2015	2015	1969	0	0	13	-	-	0.042	0	-	-	-	-	-	2015
Belize	BLZ	10	14	1	1973	1966	2010	2010	2012	2010	28	33	0	0.185	0.124	-	65	1972	2015	1965	2015	-	-
Benin	BEN	13	19	14	1962	1950	1965	2014	2012	2014	40	44	0	0.193	0.198	-	52	1961	2015	-	2015	-	-
Bosnia and Herzegovina	BIH	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Brazil	BRA	6	5	10	1958	1958	1958	2009	2009	2004	46	47	37	0.066	0.216	0.118	0	1957	2015	1957	2015	1957	2015
Brunei Darussalam	BRN	38	23	25	1957	1976	1981	2012	2012	2012	18	14	0	0.374	0.117	-	41	1956	2015	1975	2015	-	-
Bulgaria	BGR	66	66	9	1950	1950	2007	2015	2015	2015	0	0	0	-	-	-	57	-	-	-	-	-	-
Cabo Verde	CPV	30	16	30	1953	1950	1953	2011	2011	2011	29	46	29	0.102	0.184	0.097	0	1952	2015	-	2015	1952	2015
Cambodia	KHM	17	15	23	1957	1957	1983	2014	2014	2009	41	43	4	0.183	0.21	0.597	0	1956	2015	1956	2015	1982	2015
Cameroon	CMR	5	46	13	1967	1950	1965	2009	2009	2014	38	14	37	0.201	0.086	0.088	0	1966	2015	-	2015	1964	2015
Canada	CAN	43	43	24	1951	1951	1950	2015	2015	2010	22	22	37	0.031	0.056	1.827	0	1950	-	1950	-	-	2015
Chile	CHL	32	24	22	1950	1950	1950	2012	2015	2015	31	42	44	0.058	0.114	0.114	0	-	2015	-	-	-	-
China	CHN	66	66	65	1950	1950	1950	2015	2015	2015	0	0	1	-	-	0.11	0	-	-	-	-	-	-
Colombia	COL	4	10	6	1964	1950	1958	2015	2014	1966	48	55	0	0.002	0.143	-	60	1963	-	-	2015	-	-
Comoros	COM	15	-	19	1963	-	1963	2012	-	2012	35	-	31	0.251	-	0.113	0	1962	2015	-	-	1962	2015
Congo	COG	10	11	14	1965	1976	1976	2012	2012	2012	38	26	0	0.203	0.114	-	52	1964	2015	1975	2015	-	-
Congo, Dem. Rep. of the	COD	-	10	3	-	1958	1960	-	2002	1995	-	35	0	-	0.266	-	63	-	-	1957	2015	-	-
Cook Islands	COK	6	12	1	1950	1995	1991	2015	2015	1991	60	9	0	0.073	0.85	-	65	-	-	1994	-	-	-
Costa Rica	CRI	5	4	1	1986	1986	2010	2010	2015	2010	20	26	0	0.15	0	-	65	1985	2015	1985	-	-	-
Cote d'Ivoire	CIV	4	24	7	1994	1950	1984	2014	2014	2012	17	41	0	0.121	0.33	-	59	1993	2015	-	2015	-	-
Croatia	HRV	66	66	12	1950	1950	1990	2015	2015	2015	0	0	0	-	-	-	54	-	-	-	-	-	-
Cuba	CUB	6	10	13	1953	1950	1953	2011	2010	2012	53	51	0	0.004	0.041	-	53	1952	2015	-	2015	-	-
Cyprus	CYP	66	66	11	1950	1950	1957	2015	2015	2003	0	0	0	-	-	-	55	-	-	-	-	-	-
Denmark	DNK	66	66	45	1950	1950	1950	2015	2015	2015	0	0	21	-	-	1.704	0	-	-	-	-	-	-
Djibouti	DJI	4	28	1	1950	1950	2007	2014	2015	2007	61	38	0	0	0	-	65	-	2015	-	-	-	-
Dominica	DMA	9	-	3	1975	-	1975	2012	-	2012	29	-	0	0.044	-	-	63	1974	2015	-	-	-	-
Dominican Republic	DOM	6	-	7	1965	-	1953	2004	-	2004	34	-	45	0.247	-	0.065	0	1964	2015	-	-	1952	2015

Appendix 5 – Data points and associated errors in reconstructing the fleet size, per country as per Chapter 4 (Cont.)

Country	ISO3	Number of Data points			Year of first data			Year of last data			Number of interpolation - sigmoid fit			Average error - sigmoid fit (ratio to 1)			Data based on population growth (increase) or motorisation (decrease) - Unpowered only	Years extrapolated by ARIMA models					
		Art.	Ind.	Unpow.	Art.	Ind.	Unpow.	Art.	Ind.	Unpow.	Art.	Ind.	Unpow.	Art.	Ind.	Unpow.		Artisanal		Industrial		Unpowered	
Ecuador	ECU	7	29	20	1981	1953	1953	2013	2008	2014	26	27	42	0.047	0.35	0.154	0	1980	2015	1952	2015	1952	2015
Egypt	EGY	17	25	17	1950	1950	1950	2014	2014	2008	48	40	0	0.11	0.057	-	49	-	2015	-	2015	-	-
El Salvador	SLV	16	9	13	1953	2002	1953	2010	2011	2011	42	1	46	1.136	0.109	0.249	0	1952	2015	2001	2015	1952	2015
Equatorial Guinea	GNQ	8	35	14	1958	1950	1958	2013	2015	2012	48	31	0	0.357	0	-	52	1957	2015	-	-	-	-
Eritrea	ERI	6	-	6	1950	-	1962	2014	-	2009	59	-	0	0.777	-	-	60	-	2015	-	-	-	-
Estonia	EST	66	66	16	1950	1950	1953	2015	2015	2015	0	0	47	-	-	0.289	0	-	-	-	-	1952	-
Faroe Islands	FRO	20	22	-	1950	1950	-	2003	2006	-	34	35	-	0.021	0.073	-	-	-	2015	-	2015	-	-
Fiji, Republic of	FJI	4	35	8	1991	1976	1991	2011	2015	2011	17	5	0	0.017	0.271	-	58	1990	2015	1975	-	-	-
Finland	FIN	66	66	-	1950	1950	-	2015	2015	-	0	0	-	-	-	-	-	-	-	-	-	-	-
France	FRA	66	66	27	1950	1950	1989	2015	2015	2015	0	0	0	-	-	-	39	-	-	-	-	-	-
Gabon	GAB	4	6	1	1965	1950	1983	2015	2011	1983	47	56	0	0	0.042	-	65	1964	-	-	2015	-	-
Gambia	GMB	11	4	11	1965	1967	1967	2006	2008	2008	31	38	31	0.09	0	0.058	0	1964	2015	1966	2015	1966	2015
Georgia	GEO	5	39*	4	1950	1957	1953	2005	2007	1956	51	27	0	0.012	0.5*	-	62	-	2015	-	-	-	-
Germany	DEU	66	66	26	1950	1950	1990	2015	2015	2015	0	0	0	-	-	-	40	-	-	-	-	-	-
Ghana	GHA	5	47	4	1950	1954	1984	2006	2010	2007	52	10	0	0.159	0.46	-	62	-	2015	1953	2015	-	-
Greece	GRC	66	66	25	1950	1950	1991	2015	2015	2015	0	0	0	-	-	-	41	-	-	-	-	-	-
Greenland	GRL	30	4	17	1950	1950	1950	2014	2012	1967	35	59	0	0.08	0	-	49	-	2015	-	2015	-	-
Grenada	GRD	16	7	15	1946	1995	1946	2011	2011	2011	47	10	48	0.211	0.07	0.167	0	-	2015	1994	2015	-	2015
Guatemala	GTM	10	9	13	1958	1962	1958	2010	2012	2010	43	42	40	2.796	0.086	0.647	0	1957	2015	1961	2015	1957	2015
Guinea	GIN	11	9	5	1985	1961	1970	2017	2017	1998	21	47	0	0.102	0.206	-	61	1984	-	1960	-	-	-
Guinea-Bissau	GNB	34	17	29	1952	1974	1952	2012	2012	2012	27	22	32	0.081	0.065	0.27	0	1951	2015	1973	2015	1951	2015
Guyana	GUY	26	20	16	1957	1950	1957	2012	2015	2012	30	46	0	0.221	0.074	-	50	1956	2015	-	-	-	-
Haiti	HTI	4	-	1	1950	-	2008	2009	-	2008	55	-	0	0.04	-	-	65	-	2015	-	-	-	-
Honduras	HND	4	25	6	1950	1958	2007	2010	2013	2012	57	31	0	0.002	0.1	-	60	-	2015	1957	2015	-	-
Iceland	ISL	30	32	3	1950	1950	2012	2016	2016	2014	37	35	0	0.048	0.027	-	63	-	-	-	-	-	-
India	IND	8	18	11	1962	1950	1950	2010	2010	2010	41	43	50	0.105	0.107	0.029	0	1961	2015	-	2015	-	2015
Indonesia	IDN	41	34	52	1950	1950	1957	2013	2013	2015	23	21	7	0.017	-	0.01	0	-	2015	-	2015	1956	-
Iran (Islamic Rep. of)	IRN	13	7	10	1974	1974	1995	2014	2017	2014	28	36	10	0.019	0.117	0.053	0	1973	2015	1973	-	1994	2015
Iraq	IRQ	4	4	-	1950	1950	-	2011	2011	-	58	58	-	0	0	-	-	-	2015	-	2015	-	-
Ireland	IRL	66	66	26	1950	1950	1990	2015	2015	2015	0	0	0	-	-	-	40	-	-	-	-	-	-
Israel	ISR	19	23	18	1950	1950	1950	2009	2010	1967	41	38	0	0.366	0.113	-	48	-	2015	-	2015	-	-
Italy	ITA	66	66	42	1950	1950	1951	2015	2015	2015	0	0	23	-	-	0.249	0	-	-	-	-	1950	-
Jamaica	JAM	10	7	11	1962	1950	1962	2012	2012	2012	41	56	40	0.146	0.138	14.387	0	1961	2015	-	2015	1961	2015
Japan	JPN	67	67	68	1948	1948	1948	2014	2014	2015	0	0	0	-	-	-	0	-	2015	-	2015	-	-
Jordan	JOR	17	-	6	1950	-	1958	2011	-	1966	45	-	0	0.188	-	-	60	-	2015	-	-	-	-
Kazakhstan	KAZ	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Kenya	KEN	12	11	13	1979	1950	1979	2012	2012	2012	22	52	0	0.022	0.116	-	53	1978	2015	-	2015	-	-
Kiribati	KIR	6	4	3	1988	2010	1991	2008	2016	2003	15	3	0	0.441	0.004	-	63	1987	2015	2009	-	-	-

Appendix 5 – Data points and associated errors in reconstructing the fleet size, per country as per Chapter 4 (Cont.)

Country	ISO3	Number of Data points			Year of first data			Year of last data			Number of interpolation - sigmoid fit			Average error - sigmoid fit (ratio to 1)			Data based on population growth (increase) or motorisation (decrease) - Unpowered only	Years extrapolated by ARIMA models					
		Art.	Ind.	Unpow.	Art.	Ind.	Unpow.	Art.	Ind.	Unpow.	Art.	Ind.	Unpow.	Art.	Ind.	Unpow.		Artisanal		Industrial		Unpowered	
Korea, Dem. People's Rep	PRK	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Korea, Republic of	KOR	46	46	46	1952	1952	1952	2015	2015	2015	18	18	18	0.1	0.1	0.152	0	1951	-	1951	-	1951	-
Kuwait	KWT	14	16	-	1965	1960	-	2012	2012	-	34	37	-	0	0.109	-	-	1964	2015	1959	2015	-	-
Latvia	LVA	66	66	16	1950	1950	1953	2015	2015	2015	0	0	47	-	-	0.015	0	-	-	-	-	1952	-
Lebanon	LBN	7	5	9	1963	1950	1962	2006	2006	2013	37	52	0	0.084	0	-	57	1962	2015	-	2015	-	-
Liberia	LBR	4	5	3	1950	1965	1980	2004	2008	2004	51	39	0	0.013	0.167	-	63	-	2015	1964	2015	-	-
Libya	LBY	10	-	8	1957	-	1957	2008	-	2008	42	-	0	0.154	-	-	58	1956	2015	-	-	-	-
Lithuania	LTU	66	66	16	1950	1950	1953	2015	2015	2015	0	0	47	-	-	0.075	0	-	-	-	-	1952	-
Madagascar	MDG	6	23	21	1964	1966	1966	2015	2015	2012	46	27	26	0.097	0.093	0.06	0	1963	-	1965	-	1965	2015
Malaysia	MYS	63	57	63	1950	1955	1949	2014	2014	2014	2	3	2	0.078	0.03	0.056	0	-	2015	1954	2015	-	2015
Maldives	MDV	11	15	19	1972	1962	1962	2009	2016	2013	27	40	0	0.021	0.203	-	47	1971	2015	1961	-	-	-
Malta	MLT	66	66	11	1950	1950	1950	2015	2015	2007	0	0	47	-	-	0.074	0	-	-	-	-	-	2015
Marshall Islands	MHL	5	5	1	1950	1995	1991	2015	2013	1991	61	14	0	0.006	0.285	-	65	-	-	1994	2015	-	-
Mauritania	MRT	4	12	6	1986	1958	1958	2016	2015	2007	27	46	0	0.033	0.138	-	60	1985	-	1957	-	-	-
Mauritius	MUS	17	14	17	1962	1984	1962	2011	2011	2011	33	14	0	0.192	0.144	-	49	1961	2015	1983	2015	-	-
Mexico	MEX	61	61	47	1950	1950	1950	2015	2015	1997	5	5	1	0.061	0.047	0.067	0	-	-	-	-	-	2015
Micronesia, Fed.States of	FSM	8	4	1	1950	1950	1991	2015	2017	1991	58	63	0	0.021	0.013	-	65	-	-	-	-	-	-
Monaco	MCO	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Montenegro	MNE	5	7	2	1950	1950	2011	2015	2015	2012	61	59	0	0.102	0.42	-	64	-	-	-	-	-	-
Morocco	MAR	38	21	23	1950	1950	1950	2015	2015	2014	28	45	42	0.076	0.132	0.096	0	-	-	-	-	-	2015
Mozambique	MOZ	7	15	29	1967	1950	1950	2015	2015	2014	42	51	36	0.086	0.113	0.104	0	1966	-	-	-	-	2015
Myanmar	MMR	21	23	21	1978	1950	1978	2014	2014	2014	17	42	17	0.093	0.117	0.045	38	-	-	-	-	-	-
Namibia	NAM	15	14	10	1950	1952	1952	2015	2010	2009	51	45	0	0.353	0.099	-	56	-	-	1951	2015	-	-
Nauru	NRU	7	-	3	1950	-	1991	2016	-	2012	60	-	0	0.358	-	-	63	-	-	-	-	-	-
Netherlands	NLD	66	66	15	1950	1950	1950	2015	2015	1967	0	0	0	-	-	-	51	-	-	-	-	-	-
New Zealand	NZL	20	24	9	1955	1950	1950	2010	2010	2007	36	37	0	0.033	0.136	-	57	1954	2015	-	2015	-	-
Nicaragua	NIC	21	21	20	1964	1966	1966	2012	2012	2012	28	26	0	0.283	0.087	-	46	1963	2015	1965	2015	-	-
Nigeria	NGA	30	24	9	1971	1971	1983	2005	1994	2014	5	0	0	0.051	-	-	57	1970	2015	1970	2015	-	-
Niue	NIU	4	-	3	1950	-	1991	2006	-	2006	53	-	0	0.112	-	-	63	-	2015	-	-	-	-
Norway	NOR	46	64	14	1952	1952	1950	2015	2015	2015	18	0	52	0.053	-	0.047	0	1951	-	1951	-	-	-
Oman	OMN	11	12	13	1985	1985	1950	2016	2016	2014	21	20	0	0.049	0.206	-	53	1984	-	1984	-	-	-
Pakistan	PAK	24	24	31	1953	1953	1953	2011	2011	2011	35	35	28	0.302	3.696	0.376	0	1952	2015	1952	2015	1952	2015
Palau	PLW	6	-	1	1950	-	1991	2015	-	1991	60	-	0	0.016	-	-	65	-	-	-	-	-	-
Palestine / State of Palestine	PSE	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Panama	PAN	9	12	17	1973	1973	1958	2015	2015	2010	34	31	0	0.025	0.014	-	49	1972	-	1972	-	-	-
Papua New Guinea	PNG	6	32	7	1952	1952	1960	2015	2017	2010	58	33	0	0.226	0.95	-	59	1951	-	1951	-	-	-
Peru	PER	33	14	36	1950	1950	1950	2017	2016	2017	35	53	32	0.064	0.023	0.377	0	-	-	-	-	-	-
Philippines	PHL	7	20	7	1968	1959	1968	2000	2016	2000	25	37	25	0.767	0.149	0.125	0	1967	-	1958	-	1967	-

Appendix 5 – Data points and associated errors in reconstructing the fleet size, per country as per Chapter 4 (Cont.)

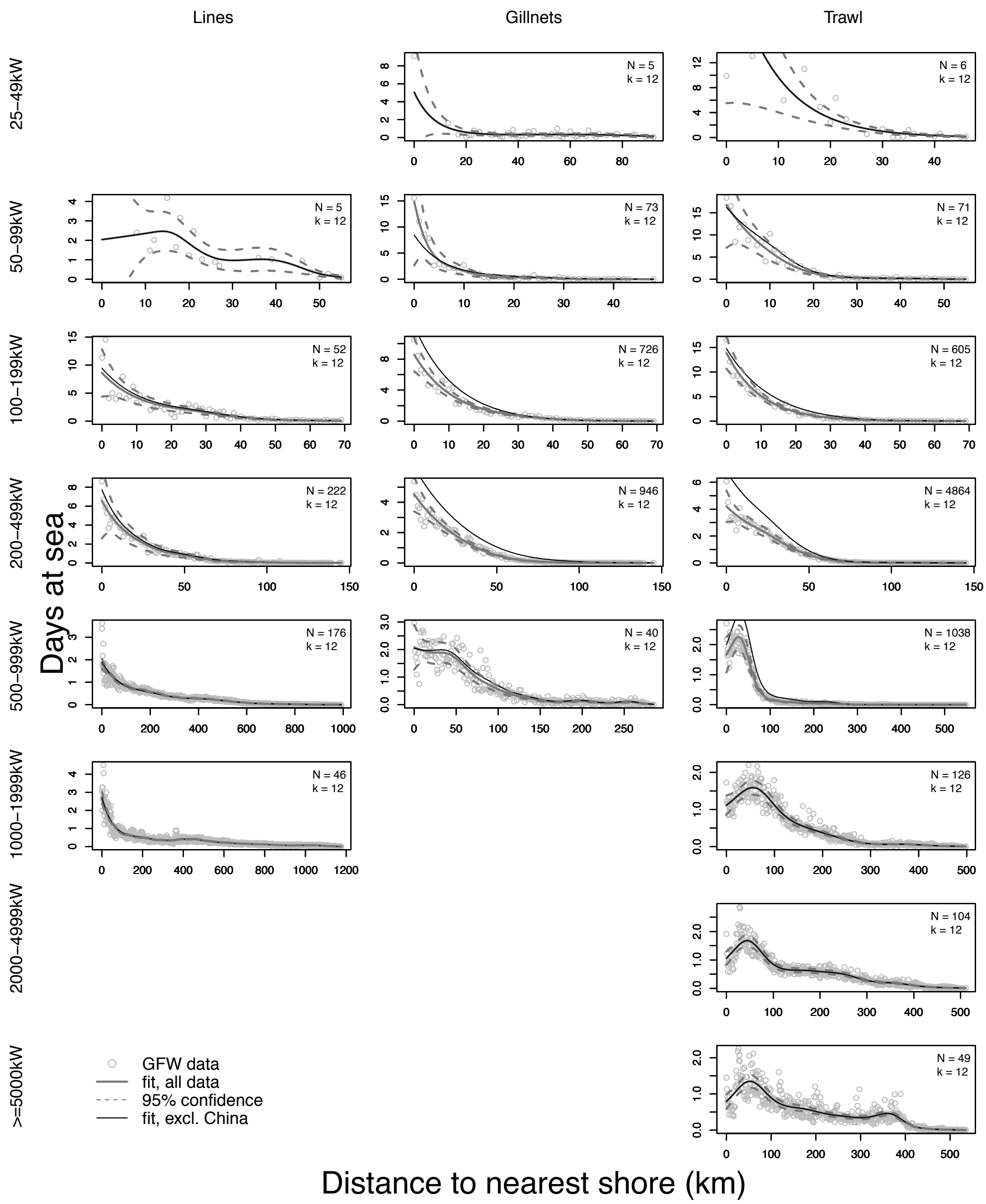
Country	ISO3	Number of Data points			Year of first data			Year of last data			Number of interpolation - sigmoid fit			Average error - sigmoid fit (ratio to 1)			Data based on population growth (increase) or motorisation (decrease) - Unpowered only	Years extrapolated by ARIMA models					
		Art.	Ind.	Unpow.	Art.	Ind.	Unpow.	Art.	Ind.	Unpow.	Art.	Ind.	Unpow.	Art.	Ind.	Unpow.		Artisanal		Industrial		Unpowered	
Poland	POL	66	66	14	1950	1950	1995	2015	2015	2015	0	0	0	-	-	-	52	-	-	-	-	-	-
Portugal	PRT	66	66	41	1950	1950	1950	2015	2015	2015	0	0	25	-	-	0.114	0	-	-	-	-	-	-
Qatar	QAT	20	4	-	1980	1950	-	2015	1993	-	16	40	-	0	0	-	-	1979	-	-	2015	-	-
Romania	ROU	66	66	12	1950	1950	2003	2015	2015	2015	0	0	0	-	-	-	54	-	-	-	-	-	-
Russian Federation	RUS	14	34	5	1953	1969	1953	2005	2014	2015	39	12	58	0.242	0.29	#######	0	1952	2015	1968	2015	1952	-
Saint Kitts and Nevis	KNA	8	-	3	1950	-	1996	2013	-	1999	56	-	0	0.033	-	-	63	-	2015	-	-	-	-
Saint Lucia	LCA	22	4	10	1962	1980	1962	2012	2012	2002	29	29	0	0.198	0	-	56	1961	2015	1979	2015	-	-
Saint Vincent/Grenadines	VCT	16	7	16	1958	2004	1958	2011	2011	2011	38	1	0	0.053	0.093	-	50	1957	2015	2003	2015	-	-
Samoa	WSM	23	13	1	1960	2003	1991	2010	2015	1991	43	0	0	0.005	-	-	65	1959	2015	2002	-	-	-
San Marino	SMR	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Sao Tome and Principe	STP	16	6	21	1951	1965	1950	2009	2009	2009	43	39	0	0.463	0	-	45	1950	2015	1964	2015	-	-
Saudi Arabia	SAU	7	5	4	1965	1960	1965	2004	2001	2015	33	37	0	0.047	0.007	-	62	1964	2015	1959	2015	-	-
Senegal	SEN	25	31	25	1958	1958	1958	2015	2015	2014	33	27	0	0.181	0.106	-	41	1957	-	1957	-	-	-
Seychelles	SYC	24	12	21	1958	1994	1963	2014	2014	2011	33	9	0	0.279	0.017	-	45	1957	2015	1993	2015	-	-
Sierra Leone	SLE	12	4	10	1965	2008	1965	2014	2016	2014	38	5	40	0.164	0.154	0.093	0	1964	2015	2007	-	1964	2015
Singapore	SGP	50	49	27	1952	1952	1950	2014	2014	1997	13	14	21	0.084	0.134	0.126	0	1951	2015	1951	2015	-	2015
Slovenia	SVN	66	66	13	1950	1950	2003	2015	2015	2015	0	0	0	-	-	-	53	-	-	-	-	-	-
Solomon Islands	SLB	4	12	4	1950	1970	1960	2015	2017	2015	62	35	52	0.025	0.121	0.001	0	-	-	1969	-	1959	-
Somalia	SOM	4	-	2	1950	-	2005	2010	-	2015	57	-	0	0.656	-	-	64	-	2015	-	-	-	-
South Africa	ZAF	6	21	17	1958	1950	1950	1966	2014	2000	3	44	0	0.015	0.065	-	49	1957	2015	-	2015	-	-
Spain	ESP	66	66	32	1950	1950	1955	2015	2015	2015	0	0	29	-	-	0.005	0	-	-	-	-	1954	-
Sri Lanka	LKA	30	30	51	1959	1959	1950	2010	2010	2015	22	22	15	0.195	0.3	0.174	0	1958	2015	1958	2015	-	-
Sudan	SDN	4	8	1	1950	1950	1997	2012	2008	1997	59	51	0	0.045	0.568	-	65	-	2015	-	2015	-	-
Suriname	SUR	15	6	13	1957	1980	1957	2009	2009	2008	38	24	0	0.154	0	-	53	1956	2015	1979	2015	-	-
Sweden	SWE	66	66	14	1950	1950	1950	2015	2015	1966	0	0	3	-	-	0.034	0	-	-	-	-	-	2015
Syrian Arab Republic	SYR	10	41	9	1981	1950	2002	2010	2010	2010	20	20	0	0.023	1.059	-	57	1980	2015	-	2015	-	-
Taiwan Province of China	TWN	66	66	66	1950	1950	1950	2015	2015	2015	0	0	0	-	-	-	0	-	-	-	-	-	-
Tanzania, United Rep. of	TZA	6	25	19	1986	1950	1962	2013	2016	2014	22	42	0	0.033	0.161	-	47	1985	2015	-	-	-	-
Thailand	THA	37	37	20	1950	1950	1950	2014	2014	2013	0	0	44	0.099	0.092	0.052	0	-	2015	-	2015	-	2015
Timor-Leste	TLS	66*	-	4	1950	-	1966	2015	-	2011	0	-	0	-	-	-	62	-	-	-	-	-	-
Togo	TGO	17	5	15	1950	1950	1980	2012	2010	2012	46	56	0	0.139	0	-	51	-	2015	-	2015	-	-
Tonga	TON	14	19	13	1950	1979	1996	2012	2017	2012	49	19	0	0.2	0.155	-	53	-	2015	1978	-	-	-
Trinidad and Tobago	TTO	11	5	5	1958	1980	1958	2006	2006	1965	38	22	0	0.206	0.262	-	61	1957	2015	1979	2015	-	-
Tunisia	TUN	32	45	23	1970	1950	1962	2015	2015	2014	14	21	0	0.128	0.053	-	43	1969	-	-	-	-	-
Turkey	TUR	34	19	25	1953	1950	1954	2015	2015	2014	29	47	36	0.183	0.115	0.801	0	1952	-	-	-	1953	2015
Turkmenistan	TKM	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Tuvalu	TUV	4	25	2	1950	1981	1991	2016	2016	2006	63	11	0	0.05	0	-	64	-	-	1980	-	-	-
Ukraine	UKR	4	47	7	1960	1950	1953	2008	2008	2010	45	12	51	0.021	0.344	0.162	0	1959	2015	-	2015	1952	2015

Appendix 5 – Data points and associated errors in reconstructing the fleet size, per country as per Chapter 4 (Cont.)

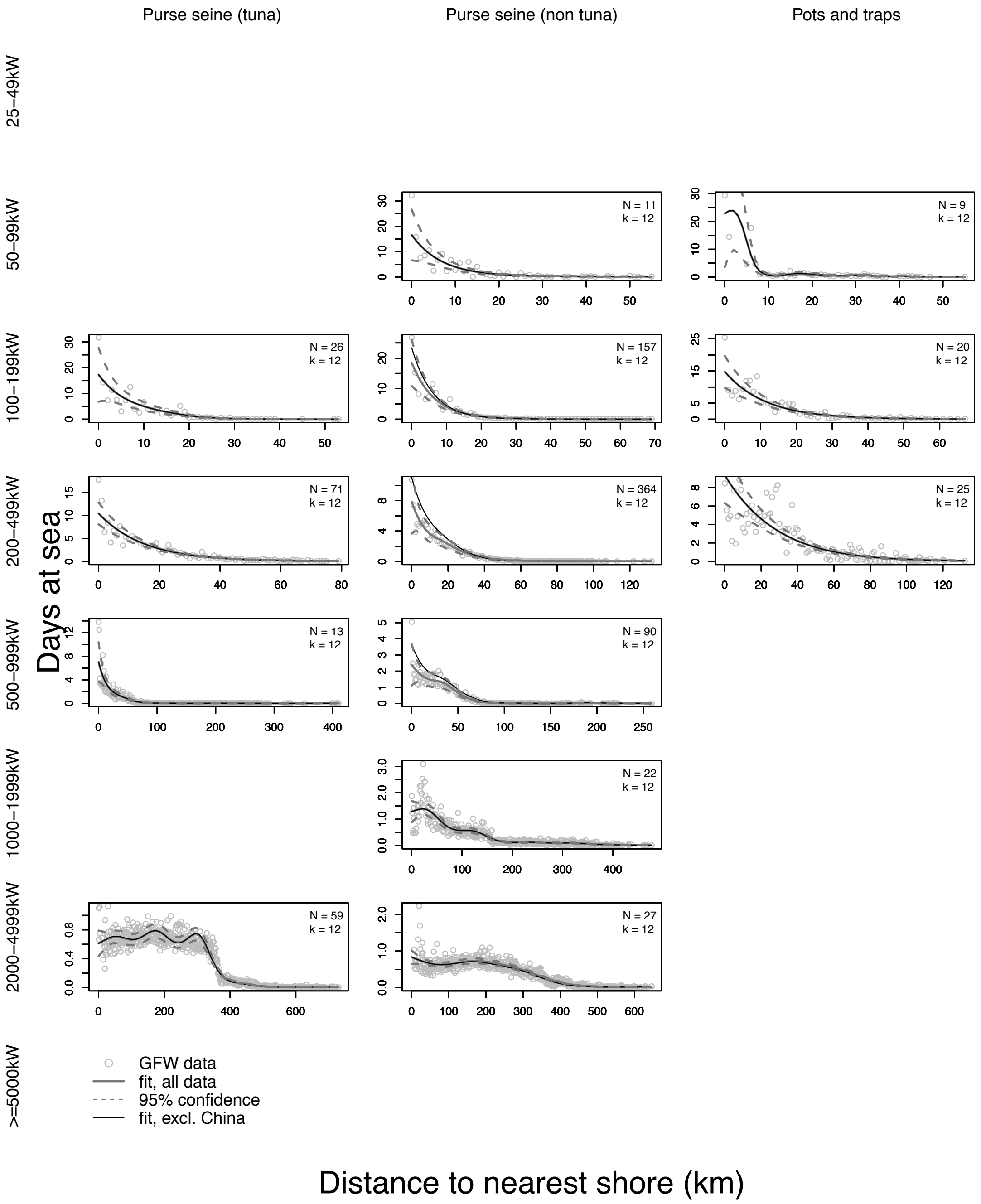
Country	ISO3	Number of Data points			Year of first data			Year of last data			Number of interpolation - sigmoid fit			Average error - sigmoid fit (ratio to 1)			Data based on population growth (increase) or motorisation (decrease) - Unpowered only	Years extrapolated by ARIMA models					
		Art.	Ind.	Unpow.	Art.	Ind.	Unpow.	Art.	Ind.	Unpow.	Art.	Ind.	Unpow.	Art.	Ind.	Unpow.		Artisanal		Industrial		Unpowered	
United Arab Emirates	ARE	21	-	-	1976	-	-	2009	-	-	13	-	-	0.107	-	-	-	1975	2015	-	-	-	-
United Kingdom	GBR	66	66	36	1950	1950	1950	2015	2015	2015	0	0	30	-	-	2.202	0	-	-	-	-	-	-
United States of America	USA	46	40	31	1950	1950	1950	2016	2016	1988	21	27	8	0.025	0.046	0.108	0	-	-	-	-	-	2015
Uruguay	URY	23	26	26	1962	1962	1962	2015	2015	2015	31	28	0	0.076	0.11	-	40	1961	-	1961	-	-	-
Vanuatu	VUT	5	14	2	1950	1950	1991	2015	2015	2003	61	52	0	0.054	0.086	-	64	-	-	-	-	-	-
Venezuela	VEN	12	16	17	1952	1952	1954	2003	2003	2014	40	36	44	0.039	0.148	0.402	0	1951	2015	1951	2015	1953	2015
Viet Nam	VNM	37	37	14	1961	1961	1950	2015	2015	2010	18	18	47	0.01	0.074	0.743	0	1960	-	1960	-	-	2015
Yemen	YEM	10	9	3	1959	1959	1992	2008	2008	2010	40	41	0	6.238	0.039	-	63	1958	2015	1958	2015	-	-

* Data assumptions lead for high number of data points/ high uncertainty

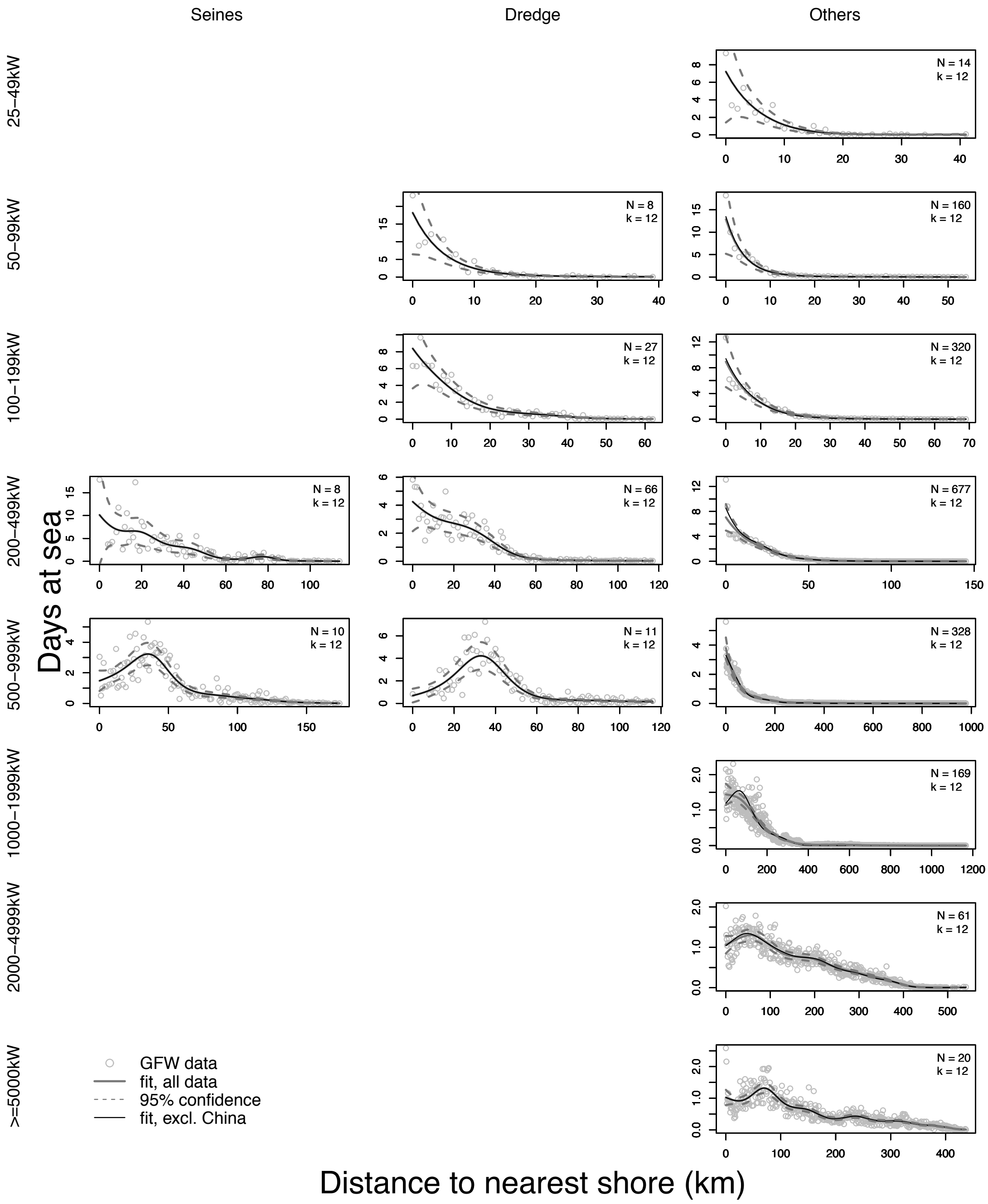
Appendix 6 – Fitting of the number of days at sea according to the distance to shore, by gear and engine power classes, GFW data, 2016. Each model is based on a Gamma-distributed GAM of smoothing coefficient k (penalized regression). N is the maximum number of vessels observed at any given distance. Plain lines correspond to the fit to data including (dark grey) or excluding (black) Chinese vessels, dotted lines correspond to the 95% confidence interval (including Chinese fleet). Only subsets containing at least 5 vessels were fitted.



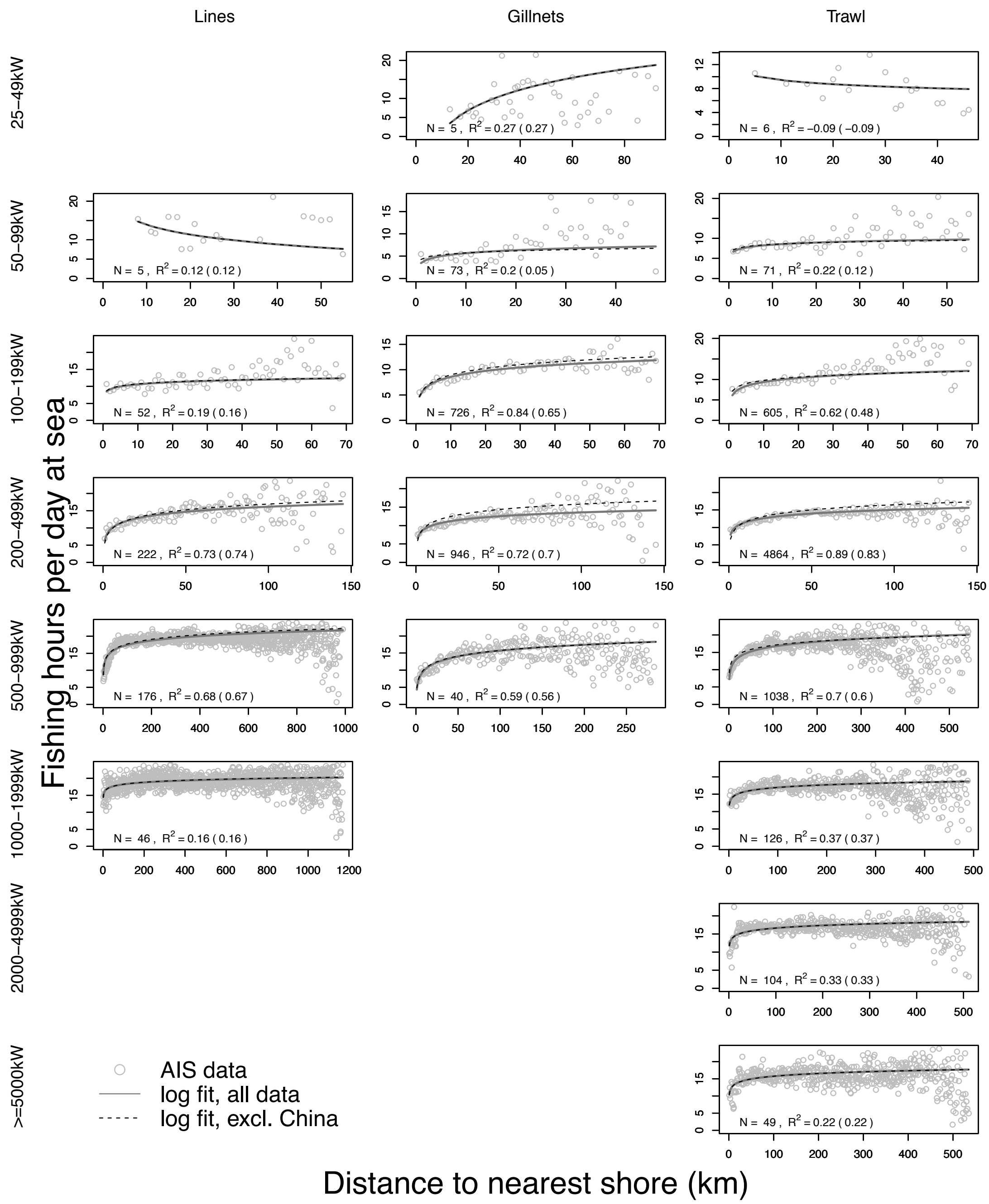
Appendix 6 – Fitting of the number of days at sea according to the distance to shore, by gear and engine power classes, GFW data, 2016. Each model is based on a Gamma-distributed GAM of smoothing coefficient k (penalized regression). N is the maximum number of vessels observed at any given distance. Plain lines correspond to the fit to data including (dark grey) or excluding (black) Chinese vessels, dotted lines correspond to the 95% confidence interval (including Chinese fleet). Only subsets containing at least 5 vessels were fitted (Cont.).



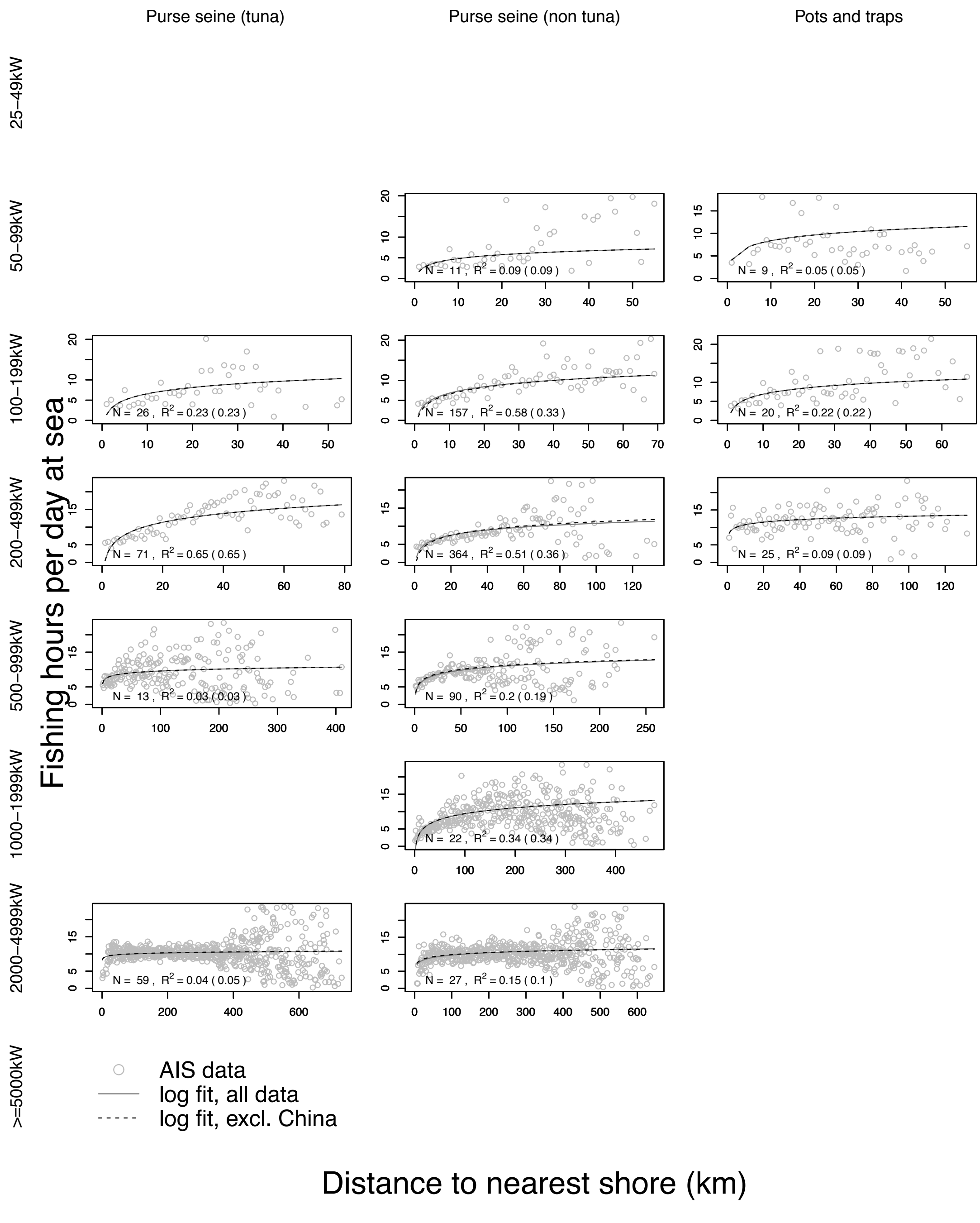
Appendix 6 – Fitting of the number of days at sea according to the distance to shore, by gear and engine power classes, GFW data, 2016. Each model is based on a Gamma-distributed GAM of smoothing coefficient k (penalized regression). N is the maximum number of vessels observed at any given distance. Plain lines correspond to the fit to data including (dark grey) or excluding (black) Chinese vessels, dotted lines correspond to the 95% confidence interval (including Chinese fleet). Only subsets containing at least 5 vessels were fitted (Cont.).



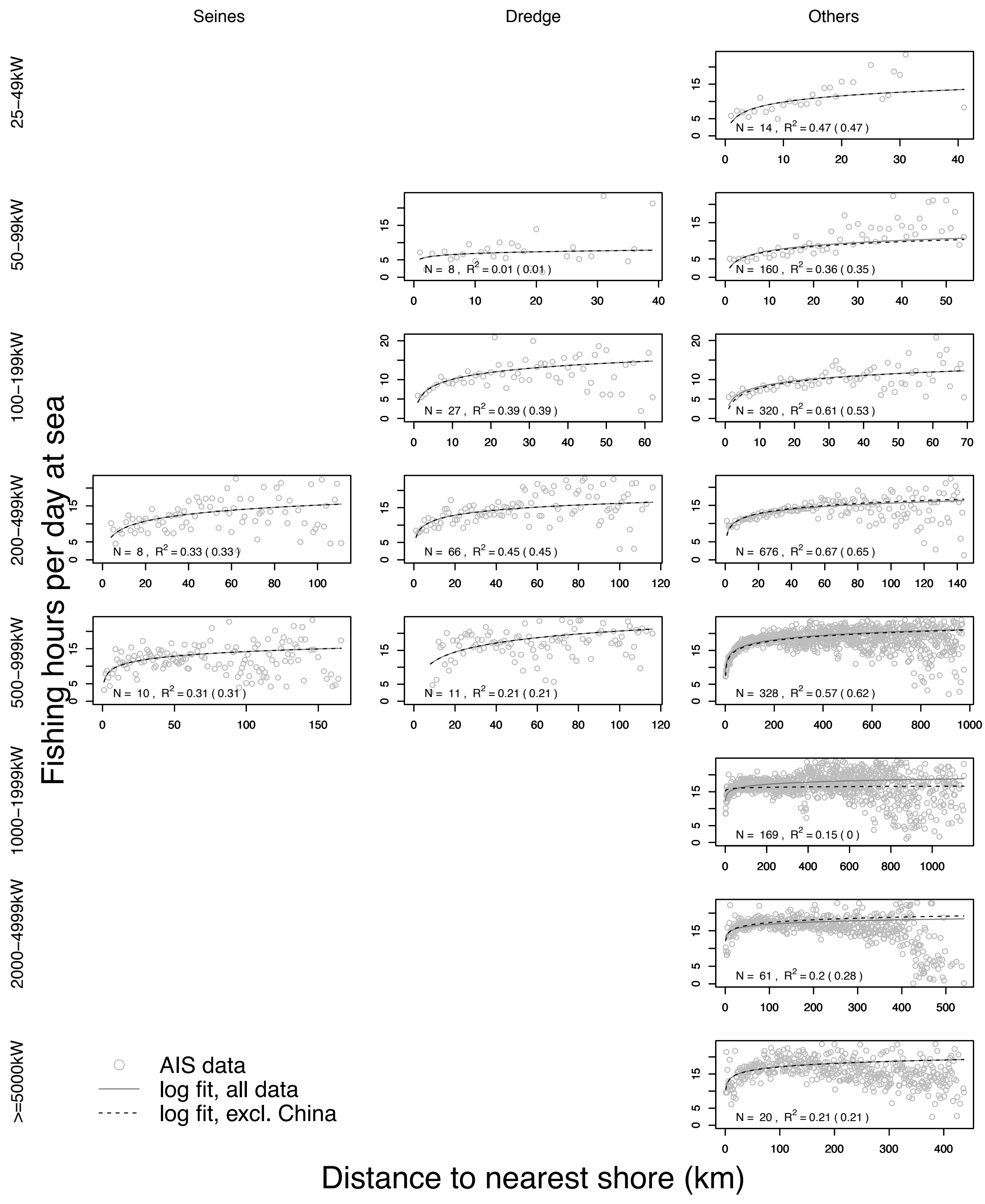
Appendix 7 – Fitting of the average number of fishing hours per day according to the distance to shore, by gear and engine power classes, GFW data, 2016. Each model is logarithmic-fitted, with the R2 given for data including (plain) and excluding (in parenthesis) Chinese fleet. N is the maximum number of vessels observed at any given distance. Plain dark grey lines correspond to the fit to data including Chinese vessels, dotted black excluding. Only subsets containing at least 5 vessels were fitted, and the fit was terminated at distance Dmax/2 to minimize the added uncertainty from the dispersion cloud at higher distances.



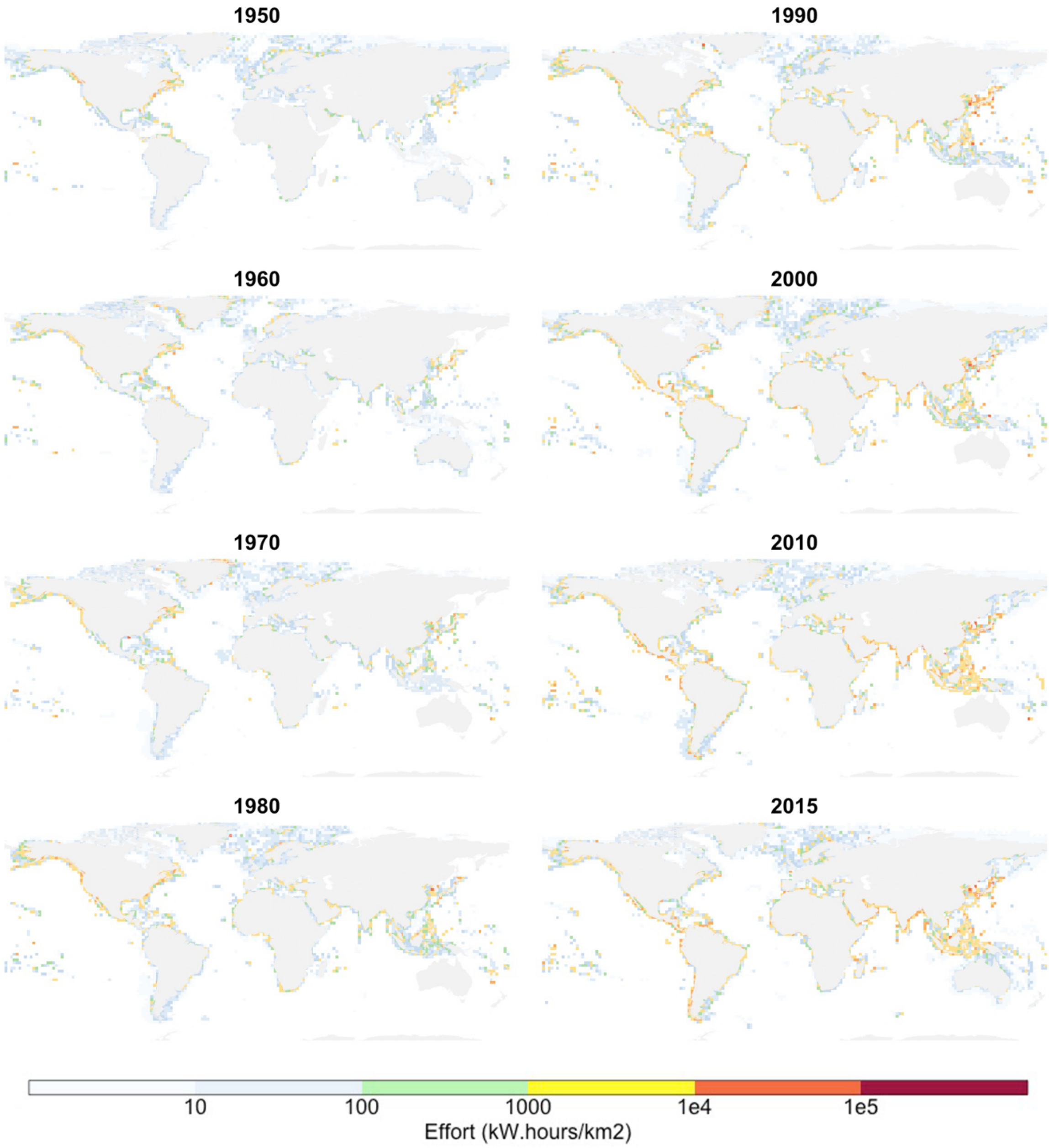
Appendix 7 – Fitting of the average number of fishing hours per day according to the distance to shore, by gear and engine power classes, GFW data, 2016. Each model is logarithmic-fitted, with the R2 given for data including (plain) and excluding (in parenthesis) Chinese fleet. N is the maximum number of vessels observed at any given distance. Plain dark grey lines correspond to the fit to data including Chinese vessels, dotted black excluding. Only subsets containing at least 5 vessels were fitted, and the fit was terminated at distance Dmax/2 to minimize the added uncertainty from the dispersion cloud at higher distances (Cont.).



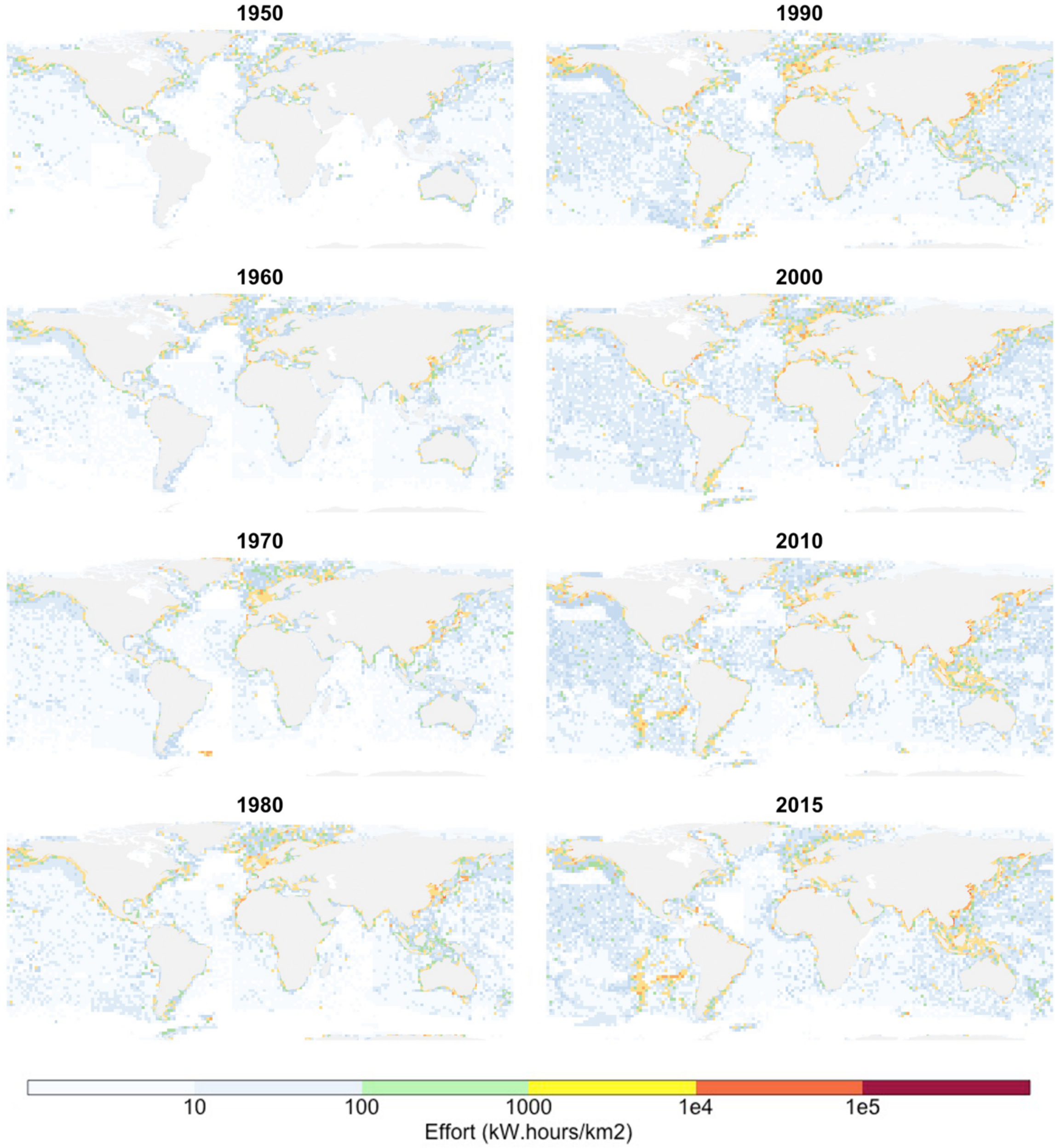
Appendix 7 – Fitting of the average number of fishing hours per day according to the distance to shore, by gear and engine power classes, GFW data, 2016. Each model is logarithmic-fitted, with the R2 given for data including (plain) and excluding (in parenthesis) Chinese fleet. N is the maximum number of vessels observed at any given distance. Plain dark grey lines correspond to the fit to data including Chinese vessels, dotted black excluding. Only subsets containing at least 5 vessels were fitted, and the fit was terminated at distance Dmax/2 to minimize the added uncertainty from the dispersion cloud at higher distances (Cont.).



Appendix 8a – Evolution of the global artisanal (motorised) fishing effort, in kW-hours per km2 of sea, 1950-2015



Appendix 8b – Evolution of the global industrial fishing effort, in kW-hours per km2 of sea, 1950-2015



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